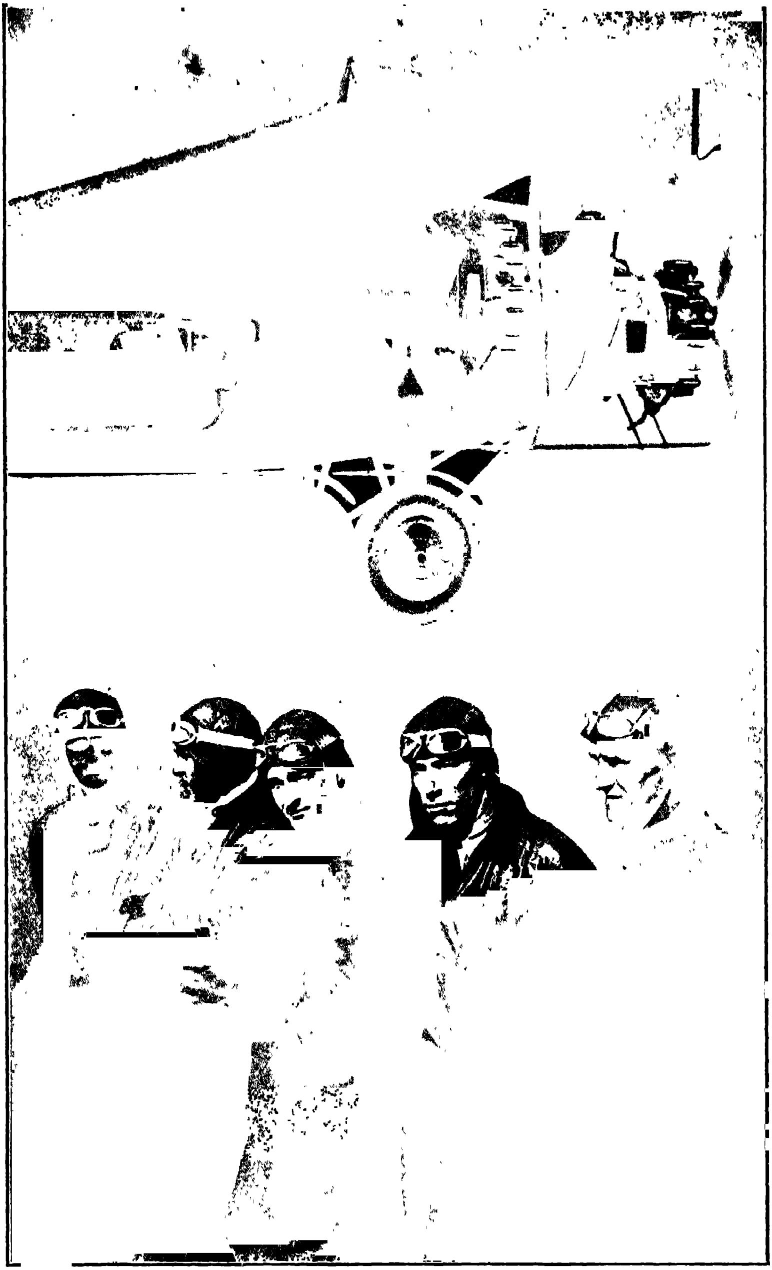
MODERN AVIATION ENGINES

VOLUME TWO



The U. S. Army "Question Mark" in Flight Showing Srgt. Hoey Climbing Out on a Cat Walk to Make Minor Adjustment to Outboard Engine While on Record-Breaking Endurance Flight. The Crew of the "Question Mark" Shown Below, Reading from Left to Right—Major Spatz, Captain Eaker, Lieut. Halverson, Lieut. Quesada and Srgt. Hoey.

MODERN AVIATION ENGINES

DESIGN—CONSTRUCTION—OPERATION AND REPAIR

A COMPLETE, PRACTICAL TREATISE OUTLINING CLEARLY THE ELEMENTS OF INTERNAL COMBUSTION ENGINEERING WITH SPECIAL REFERENCE TO THE DESIGN, CONSTRUCTION, OPERATION AND REPAIR OF AIRPLANE POWER-PLANTS; ALSO THE AUXILIARY ENGINE SYSTEMS, SUCH AS LUBRICATION, CARBURETION, IGNITION AND COOLING

It Includes Complete Instructions for Engine Repairing and Systematic Location of Troubles, Tool Equipment and Use of Tools, also Outlines the Latest Mechanical Processes

IN TWO VOLUMES

164

BY

MAJOR VICTOR W. PAGÉ, U. S. AIR CORPS RESERVE

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Author of Modern Aircraft, Everybody's Aviation Guide, Etc.

Describes Many Typical American and European Engines and Their Installation. Contains Valuable Instructions for all Aviation Students, Pilots, Mechanicians, Flying Field Engineering Officers and All Interested in the Design, Construction and Upkeep of Airplane Powerplants.

VOLUME TWO

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PREFACE

In presenting this treatise on "Modern Aviation Engines," the writer realizes that the rapidly developing art makes it difficult to outline all latest forms or describe all current engineering practice. This exposition has been prepared primarily for instruction purposes and is adapted for students who wish to become aviators or aviation mechanicians, and for mechanics in other lines who wish to enter the aviation industry as experienced aviation engine maintenance and repair men. Every effort has been made to have the engineering information accurate, but owing to the diversity of authorities consulted and use of data translated from foreign language periodicals, it is expected that some errors will be present. The writer wishes to acknowledge his indebtedness to many firms for photographs and helpful descriptive matter and endeavor has been made in every case to give credit to the firm furnishing such data, also to experts in various lines that have been quoted in this treatise. Special attention has been paid to instructions on tool equipment, use of tools, trouble "shooting" and engine repairs, as it is on these points that the average aviation student is weakest. Only such theoretical consideration of thermodynamics as was deemed absolutely necessary to secure a proper understanding of engine action (after consulting several experienced instructors) is included, the writer's efforts having been confined to the preparation of a practical series of instructions that would be of the greatest value to those who need a diversified knowledge of internal-combustion engine construction, operation and repair, and who must acquire it quickly. The engines described and illustrated are all practical forms that have been fitted to airplanes capable of making extended flights and may be considered fairly representative of the present state of the art.

Considerable space is devoted to the leading war-time engines in both the water- and air-cooled forms because some of these are still in use and also because these are the types from which our present day perfected engines have been developed and a review of their characteristics should be of value in showing the reader what has been done in the past, so he can better understand the possibilities of the future. As aviation and the increasing use of aircraft has practically eliminated national boundaries, this book has been made international in scope and many practical and successful European engines have been illustrated and described along with our own American product.

VICTOR W. PAGÉ.

ACKNOWLEDGMENT

One of the most important branches of aeronautical engineering is that dealing with powerplant design, construction, installation and repair and aeronautical engineers may be divided into two main groups, "plane" men and "engine" men. The division of the engine men is in three main classes; designers, builders or production men and field men who are concerned with installation, maintenance and repair. Specialists in any of the subdivisions find that it takes all their time to become familiar with the many phases of the subject they are interested in. While the author has had a broader experience than many of the specialists, it is only because he has been identified with aviation since its inception and because of particularly fortunate circumstances while serving on the Staff of the Chief of the Air Corps during the World War, which offered unexcelled opportunities to obtain experience on a larger scale than normal peace time activities permitted.

Regardless of this experience, the author has found it desirable and even necessary to consult other authorities and specialists in order to check up on his own opinions and experience and every effort has been made in this treatise to present both sides of every controversial subject. The reader may select the line of reasoning that best applies to the case under consideration and no matter what he finally accepts, he will find ample authority as a basis for his line of thought. In preparing this work the author has made references to the authority responsible for the opinions or information presented and in every case due acknowledgment is made in the text to the expert quoted, when the opinions are not those of the author.

There are many sources of aeronautical data at the present time besides the manufacturers of airplanes, engines and auxiliary apparatus. Government documents and publications of the Engineering Division, U. S. Army Air Corps, with laboratory facilities at Wilbur Wright Field, Dayton, Ohio; and also those of the National Advisory Committee for Aeronautics, Washington, D. C.; have been consulted freely and brief excerps and abstracts from these public documents have been used to bring out points in the text that were considered in greater detail in reports of experts and specialists. The United States Bureau of Standards, and the United States Department of Commerce, Washington, D. C., have also published much valuable data in the form of reports issued in co-operation with the Government agencies previously mentioned.

The membership of the Society of Automotive Engineers, Inc., includes many aeronautical experts and specialists and much valuable data has been published in the *S. A. E. Journal* on aviation and kindred subjects. The publications *Aviation* and *Aero Digest* of New York City were also of great value and references to editorial opinions and descriptions of aircraft engines, have also been included to justify and support some of the opinions of the author. Such leaders in the industry as the Goodyear-Zeppelin Co.,

Akron, Ohio; the Curtiss Aeroplane and Motor Company, Inc., of Garden City, New York; Packard Motor Car Co., Detroit, Mich.; the Wright Aeronautical Corporation, Paterson, New Jersey; Pratt & Whitney Aeronautical Corporation, Hartford, Conn.; as well as numerous other firms whose products are described in the text, furnished valuable illustrative and descriptive data. The Bureau of Aeronautics, U. S. Navy and the Information Section, U. S. Army Air Corps, also furnished material pertinent to service planes, airships, and engines. A number of early engines were described in Angle's *Airplane Engine Encyclopedia* which was also referred to in preparing this volume.

The writer desires to acknowledge the valuble assistance obtained from the sources mentioned as they have greatly supplemented the material in the original aviation engine instruction papers prepared for students and Army mechanics during the late War and the author's experience in aviation since its inception over two decades ago that forms the ground work for this treatise. The character of co-operation obtained cannot fail to promote knowledge of aviation and proper public appreciation of its great possibilities.

The public spirit and enthusiastic co-operation of the publisher of this treatise in going to an unusual expense in financing extended research work of the author and for the numerous excellent special illustrations that accompany the text, in order to help the cause of aviation and also in giving the writer *carte blanche* in the preparation of an unusually complete work without allowing purely business reasons to limit the size and scope, is also worthy of comment and appreciative acknowledgment.

VICTOR W. PAGÉ.

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CHAPTER XXVIII

SMALL AIR-COOLED ENGINES

Henderson Conversion—Wright-Morehouse Engine—Mercedes Benz Type F 7502 Engine—The Bristol "Cherub" Engine—A.B.C. Scorpion Mark II—Scorpion Installation—Instructions for First Run—Scorpion Engine Inspection—Running Engine—Daily Inspection—Instructions for Top Overhaul—Removing Cylinder Unit—Reassembly of Cylinder Unit and Pistons—Dismantling Engine—Reassembly after Overhaul—Meteormotor Radial Engine—Szekely SR3.

Henderson Conversion.—The experimenter with small and light airplanes has been somewhat handicapped in the past because of the lack of a simple, efficient and economical engine of small capacity and converted motorcycle engines have been used in experimental work. These have not always been satisfactory because they were heavy in proportion to their power output though much superior to any of the small automobile powerplants available for the purpose. Most motorcycle engines were deficient in power output and special aircraft engines were too expensive. The Henderson four-cylinder "De Luxe" model motorcycle engine possesses many of the characteristics of a first-class light plane engine, and by evolving a special conversion that allows the propeller to be driven direct from the crankshaft, the Heath Company have made it possible to use this low priced and popular engine successfully in their "Parasol," a light weight sport monoplane. All Henderson motors, furnished as stock equipment on "Parasol," are equipped with high pressure oiling system. They have been run for many hours on the test block and in planes, giving them a severe test, and have been found to stand up remarkably well. Henderson engines were used in many light plane races in the past few years, and have stood the test. They are remarkable little engines that are unusually well suited for use in inexpensive sport planes. It is said they will drive the plane 35 miles on a gallon of gasoline. The Henderson "De Luxe" motor develops 23 horsepower at 3,000 r.p.m., and weighs complete with propeller only 117 pounds. It is low in upkeep because it uses standard motorcycle engine parts that are obtainable in any part of the country. The engine is so well known as used in motorcycles that a detailed description is not deemed necessary. The accompanying illustration Fig. 465 shows a Henderson motorcycle engine with special Heath propeller and propeller conversion, installed in Heath "Parasol" fuselage. The engine mounting employed is so simple that the mounting can be completely dismantled by removing only four bolts. This makes it possible to adapt it to different types of engines without great structural changes. A fuel tank of 3.3 gallons capacity is fitted in the center above the wings.

While the Henderson motorcycle engine is ideal for sport use, it is often desirable to use a more powerful engine to obtain greater speed, where the plane is used for exhibition work. Where such superperformance is

desired, and where cost is no object, the Wright-Morehouse engine, developed especially for light plane use has been recommended by some authorities. This engine is of the two-cylinder opposed type, air-cooled, and develops 29 horsepower at 2,500 r.p.m. It weighs but 89 pounds, and due to its peculiar design it is easily and effectively streamlined when in-

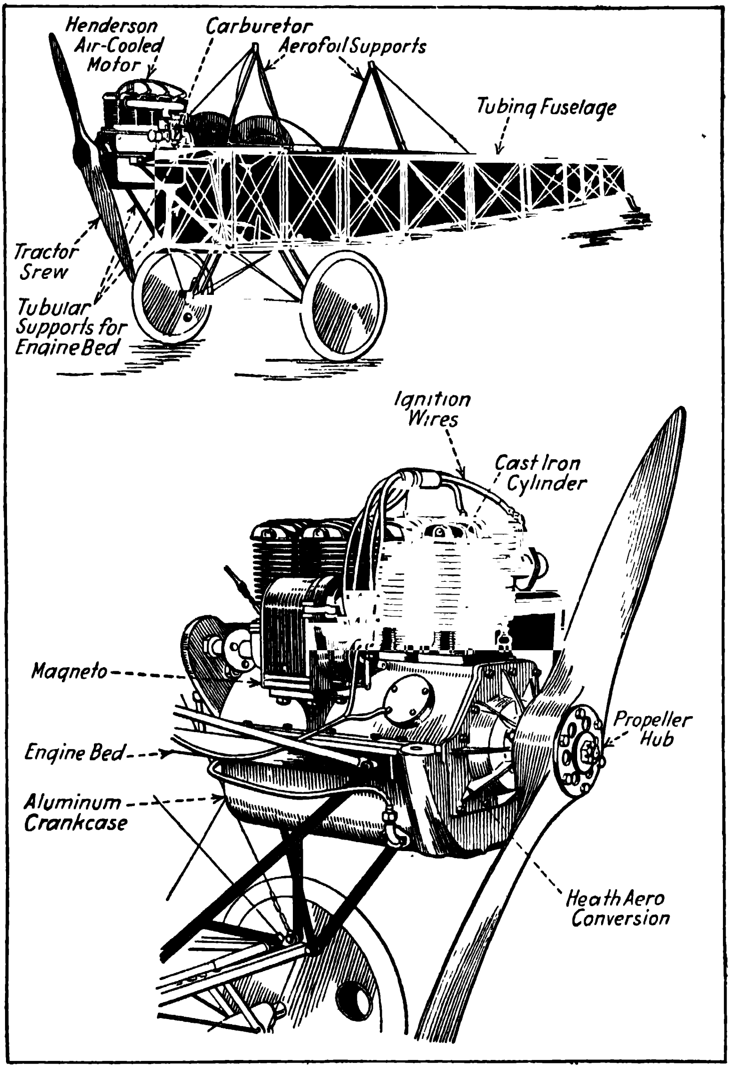


Fig. 465.—How Henderson Motorcycle Engine with Special Conversion is Installed in Heath "Parasol" Monoplane. The Top View Shows Complete Fuselage and Relation of Engine Supports to Other Parts of the Structure. The Lower View is the Close-Up of the Engine, the Small Size of Which Can be Understood by Comparing it with the Magneto.

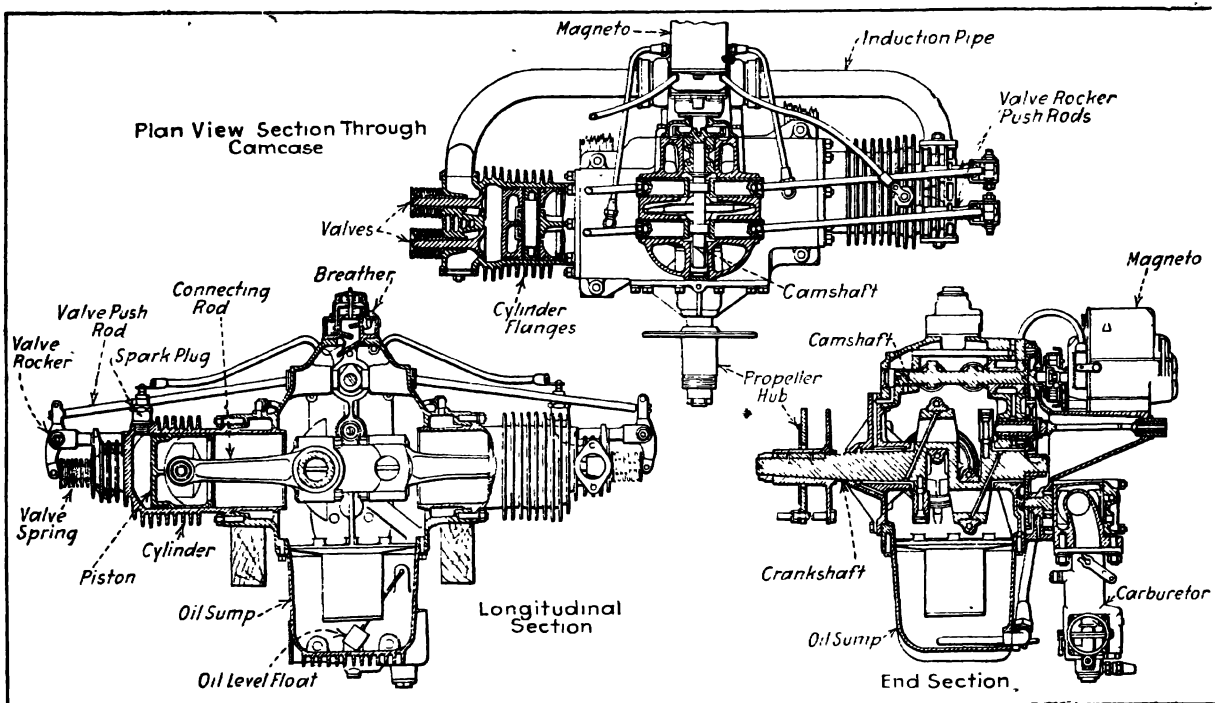


Fig. 466.—Sectional Drawing Showing Construction of Wright-Morehouse Aviation Engines with All Important Parts Designated for Easy Reference. These Engines Are Now Known as the Lincoln Rocket.

stalled in a small plane. The Wright-Morehouse engine has met with great success in recent air races and has proven reliable and efficient, but at this writing it is not yet in large scale production but it is expected that the demand will increase and warrant the manufacturers in producing this efficient and well designed engine in quantities.

Wright-Morehouse Engine.—This is a light opposed cylinder type designed especially for light airplanes. It is clearly shown in the sectional engineering drawing at Fig. 466 which outlines all details clearly for the technical or engineering student. The cylinders are cast iron with integral cooling fins and valve seats. They are attached to the crankcase through the cylinder flange, about half way up the barrel, their location being made by two pilots, one at the flange and one at the end of the barrel. Between these two pilots the crankcase is cored to form closed passages when the cylinder is in place. Bypass oil from the pump is led into these passages serving to cool the cylinder skirts before returning to the sump. Tulip shaped valves are used, both intake and exhaust having ample diameter and lift. The valve springs are helical and made from special heat treated spring steel wire. Adjustable push rods with ball and socket joints at each end actuate the forged steel rocker arms. Case hardened steel cam followers operate directly on the camshaft. The push rods are so recessed in their sockets that they cannot come out in flight, while the rocker arms are supported on individual forged brackets studded into the cylinder heads.

The crankshaft is a steel drop forging, counterbalanced to reduce vibration, and having two throws at 180 degrees. It is drilled for oil passages, giving pressure lubrication to all bearing surfaces. The camshaft is mounted directly over the crankshaft and parallel to it. The camshaft gear is integral with the shaft and is driven by one idler gear at half engine speed. The idler gear is extended to form the tachometer drive connection. The camshaft and idler gear are both assembled through the rear cover plate. Both crankshaft and camshaft are mounted on large plain bearings of ample size. These bearings are grooved for oil passages to the crankshaft and crankpin bearings. The crankcase is an aluminum casting of especially clean lines.

The connecting rods are of forged duralumin and are of H section. The wristpin bushings are of bronze, shrunk into the connecting rod. The crankpin bearings are babbitt applied directly to the rods. The pistons are the straight cylindrical type, made of aluminum and having crossed ribs supporting the flat piston head. Four rings, three above and one below the piston pin, are used. The hollow piston pins float in both rods and the pistons, bronze end plugs being used to prevent cylinder scoring. The piston pins and cylinder walls are lubricated by oil spray from the crankpin bearings.

A gear pump in the cover plate gives force feed lubrication to the main and connecting rod bearings, idler gear bearing, and camshaft bearings. The sump is equipped with an oil level indicator, oil strainer, and thermometer connection. Cooling fins are cast on the bottom to keep the oil temperature correct. The sump holds about three quarts of oil and is filled through the breather. A single Scintilla magneto, driven direct from the rear end of the camshaft, fires a single plug in each cylinder. An

impulse starter coupling between the magneto and the camshaft, insures a quick turn for the magneto in starting. The fuel mixture is supplied by a special carburetor through an oil jacketed elbow attached to the rear cover plate. Individual manifolds carry the mixture to each cylinder. Four holding-down bolts fasten the engine to the bearers. All the controls are at the rear of the engine, thus simplifying the installation in the plane.

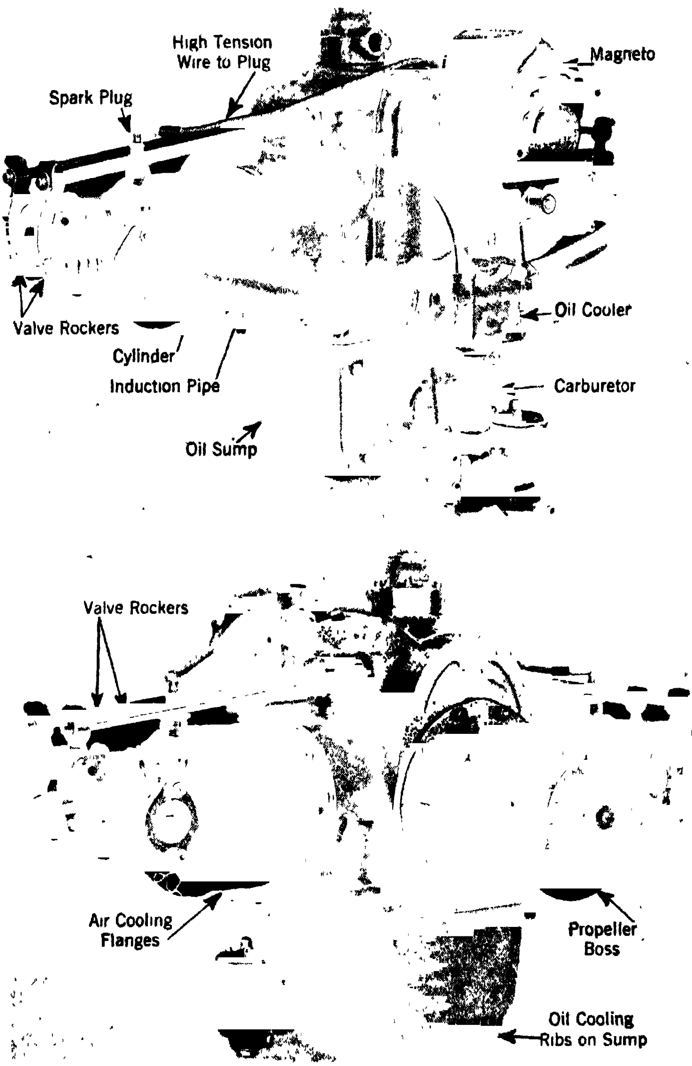


Fig. 466A.—The Lincoln Rocket, Formerly the Wright-Morehouse Two Cylinder Aviation Engine. At Top—Rear View Showing Ignition Magneto and Carburetor. At Bottom—Engine Viewed from Propeller End.

SPECIFICATIONS—LINCOLN ROCKET

Bore	3.75 in.
Stroke	3.625 in.
Displacement (1.31 liters)	80 cu. in.
Compression ratio	5 : 1
Rotation	anti-clockwise
Weight, dry	89.5 lb.
Power at 2500 r.p.m.; average	29 hp.
guaranteed	25 hp.
Fuel-consumption at 2500 r.p.m.; average	2 5 gal./hr.
guaranteed	0.55 lb./hp.-hr.
Shipping weight	155 lb.

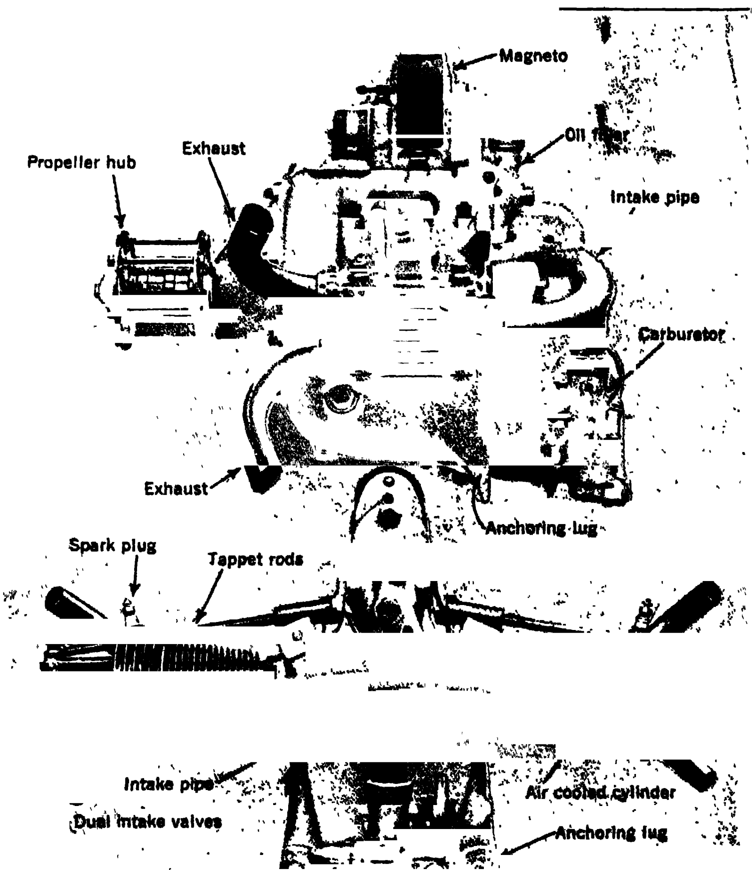


Fig. 467.—The Mercedes-Benz Twenty Horsepower Two-Cylinder Engine is a High-Speed Type with Geared Propeller Drive.

Mercedes-Benz Type F-7502 Engine.—The underlying principle of the design of this engine, in the construction of which use is made exclusively of materials of the highest quality, was to create for small sports airplanes a particularly light, simple, and thoroughly reliable machine, on which the pilot could rely absolutely in all circumstances. When the "Mercedes-Benz" Works undertook the task of putting this principle into practice, they did so with the assistance of an experience of many years in the construction of engines and aircraft and the engine illustrated at Figs. 467 and 468 is the result of this development. The chrome-nickel steel crankshaft works in a crankcase made of Silumin, in which it runs in two roller bearings. The two steel cylinders have a bore of 75 millimeters and a stroke of 100 millimeters. They are opposed diametrically, screwed horizontally into the crankcase, and fitted with grey cast-iron cylinder heads. In each cylinder head are fitted two chrome-steel inlet an two chrome-steel exhaust valves, which are operated by a camshaft running in the crankcase, through tappet rods and rockers. The camshaft, as well as the "Bosch" magneto ignition and the geared oil pump, are driven by spur gearing from the crankshaft. The cooling of the ribbed cylinders is effected by air circulation, while provision is made for the lubrication of the crankshaft and of all transmission parts by means of a geared pump located in the bottom half of the crankcase, which receives a constant supply of fresh oil from a small piston pump. The oil which collects in the bottom part of the crankcase returns to the oil pump after purification in an oil strainer. The aluminum pistons are lubricated by splash lubrication. The fuel is supplied through a "Mercedes-Benz" carburetor with main and slow running jets. The air required by the carburetor is drawn in through a preheater fitted on the crankcase, in which it is heated before its admission into the carburetor. The crankshaft drives the propeller through the intermediary of a planetary gear with a ratio of three to one. This engine is used on the Klemin-Daimler monoplane, which has made remarkable flying records.

The principal dimensions and working data are supplied by the following table.

Number of cylinders	2
Bore	75 mm.
Stroke	100 mm.
Capacity of cylinders	884 cc.
Length	590 mm.
Width	775 mm.
Height	470 mm.
Normal speed of the crankshaft	3000 r.p.m.
Normal speed of the propeller	1000 r p.m.
Power output	20 hp.
Power output in an atmospheric density of 1.25	22 hp.
Fuel consumption per hp.-hour	300 grams
Oil consumption	19 grams
Weight of the engine without oil or propeller	48 kilos
Capacity for oil	1.7 liters

The Bristol "Cherub" Engine.—This is a very popular engine for light airplanes in England. The engine has recently been submitted successfully

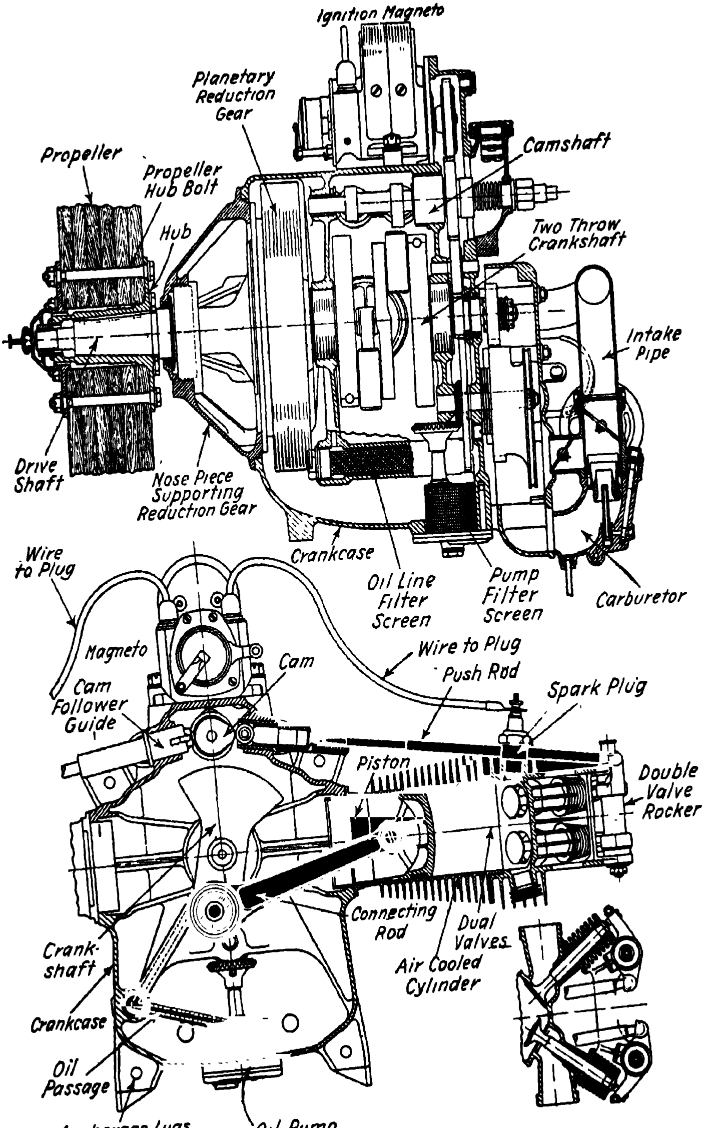


Fig. 468.—Sectional Views Showing Design and Construction of the Mercedes-Benz Two-Cylinder Aviation Engine.

to the latest British Air Ministry 100-hour Type tests. It completed this test in ten nonstop periods of ten hours each, without any hitch, stoppage, adjustments or replacements. On the last hour, the engine held 36.6 brake horsepower at 3,200 r.p.m. The average fuel-consumption throughout the test was .586 pints per brake horsepower per hour and the average oil consumption .026 pints per brake horsepower hour. At the conclusion of the test, the engine was stripped and found to be generally in excellent condition. The Bristol "Cherub" engine is of the two-cylinder opposed type and has a total swept volume of just under 1,230 cubic centimeters.

The crankshaft is a case hardened alloy steel stamping of ample dimensions, carried in four bearings; the crankcase is an aluminum casting, split vertically on the engine center line and provided with separate front and rear covers. There are three main bearings. The front one is of the deep groove type, located in the nose of the conical front cover, and transmits the propeller thrust from the crankshaft to the case. The other two are of the double row self aligning type, and situated adjacent to the crank throws, one in front and the other in behind, and are housed in the front and rear half crankcases, respectively. The tail end of the shaft is supported in the rear cover by a plain white metal bearing which provides an oil seal, allowing oil to be supplied through the hollow tail end and drilled oilways to the big end of the bearings. On the shaft between the two rear bearings, a spur wheel and two spiral gear wheels provide drives for the camshaft, tachometer and magneto and oil pump, respectively.

Connecting rods are alloy steel forgings with hardened liners, pressed into the big ends, the proportions of which are such that the rods may be threaded over the shaft. When in position, the split bronze floating bushes are inserted and the two halves secured to each other by high tensile steel screws which are locked by split pins. The pistons are of aluminum alloy, fitted with three rings, the lower one of which serves as a scraper and returns surplus oil from the cylinder walls through drain holes in the piston skirt. The hollow gudgeon pins float, both in the piston bosses and in the connecting rod small ends and are located endways by bronze buttons pressed into their open ends.

The cylinders have steel barrels, but the inlet and exhaust passages are formed in the aluminum alloy heads which also carry the screwed-in alloy steel valve seats, valve guides, valves and springs. A deep spigot for the head is provided on the barrel with a flange to which the head is bolted by a copper ring spigotted and very carefully fitted in annular grooves cut in the head and barrel flanges. As the rates of expansion of aluminum and steel are different, great difficulty is usually encountered in the maintenance of a really gas-tight joint with this type of head. In the Cherub heads, this difficulty has been entirely overcome by inserting packing pieces of a special alloy, having an unusually low rate of expansion, between the cylinder heads and the heads of the securing bolts. This arrangement, combined with the copper ring joint, has proved so satisfactory that the ends of the bolts are riveted over their nuts, the head and barrel being regarded as one unit which need never be disturbed. The cylinders are secured to the crankcase by a spigotted and flanged joint, a packing ring serving to make the joint oil tight.

Inlet and exhaust valves are of cobalt-chrome steel and are interchangeable, and three concentric springs are used on each valve. The valve operating gear is somewhat unusual and has distinctive features of considerable importance. The camshaft, which, with its four cams is machined from the solid, runs across the crankcase below the crankshaft and is driven by plain spur gears of ample dimensions. The cams are of the constant acceleration type. The valves are operated by rocker shafts which run parallel to the cylinder.

The carburetor is a special type of Zenith with hand operated altitude control of the extra diffuser air type and is bolted to a cast aluminum in-

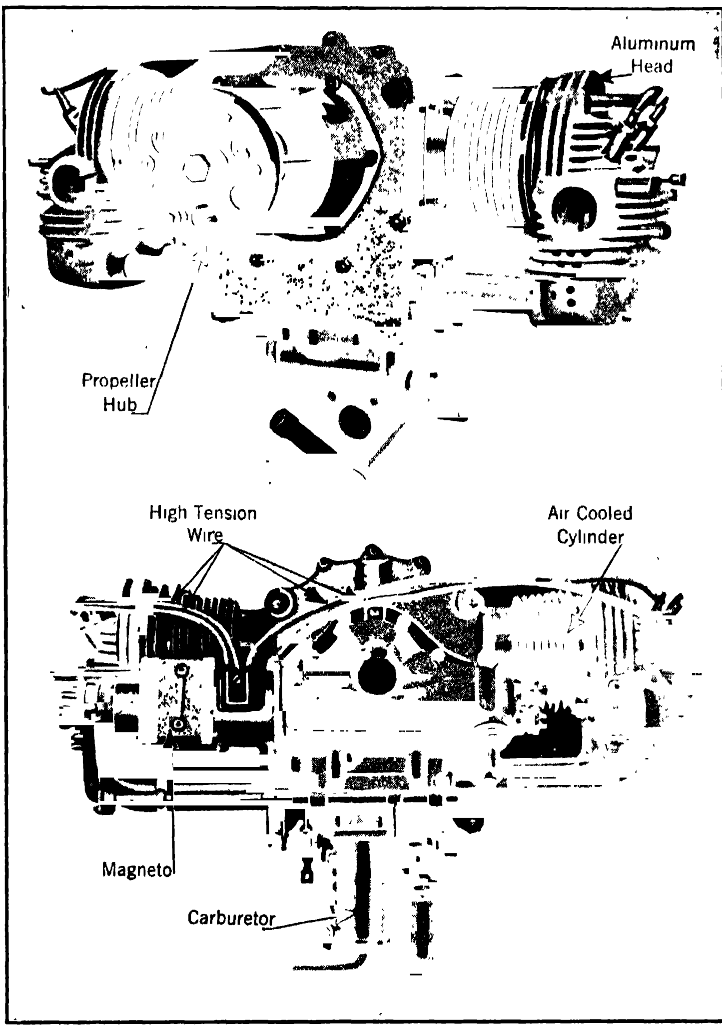


Fig. 469.—The Bristol "Cherub" Aviation Engine, an Efficient English Design for Low-Power Sport Planes.

duction "T" piece which is attached by studs and nuts to a broad facing on the underside of the magneto and pump housing on the rear cover. The throttle and magneto advance and retard are inter-connected by a suitable arrangement of levers and links. The altitude control is independent except that it is closed automatically if the throttle is closed. The air intake to the

Fig. 470.—Showing Method of Installing Bristol "Cherub" Engine in the Johnson Twin 60 Biplane in which One Engine was Used on Each Side of the Fuselage, Suspended by Engine Bed Between the Wings.

carburetor is an exhaust jacketted steel elbow. The induction pipes run from the "T" piece parallel to the cylinders and are fitted into it with airtight expansion joints, and are provided with bosses to take primer jets. The engine is mounted from screwed extensions on the ends of the four crankcase bolts at each corner of the crankcase. A standard connection

for a tachometer is arranged on the port side, above the magneto. This engine is shown at Fig. 469. The cylinder bore is 3.5 inches, the stroke 3.8 inches. It has a piston displacement of 75 cubic inches. The compression ratio is 5.5 to 1. The dry weight is given at 100 pounds, or 3.1 pounds per horsepower. The length is nine inches, the width 25.5 inches and the height twenty inches. The center to center of engine bearers is 7.4 inches.

The method of installation on the Johnson Twin 60 Biplane, where the motors are carried between the wings and drive pusher air screws is clearly shown at Fig. 470. The simple mounting of steel tubing supports and braces can be easily seen, support tubes extending from the rear wing spar near the strut fitting and bracing members of triangular form joining the front and rear interplane struts. The fuel tanks are carried in the upper wing, the wedge-shaped oil tank is placed ahead of the motor crankcase as shown.

The A. B. C. 34-40 Brake Horsepower "Scorpion" Mark II.—This twin-cylinder, horizontally opposed, air-cooled engine, has been specially designed for use in light airplanes, hydro-gliders, etc., and is a good example of English design said to be in excellent balance mechanically and singularly free from any periods of vibration. Normally the engine is a "tractor," running clockwise looking from the cockpit, but it can be supplied as a "pusher" if required, and in this form it has been mounted in machines and flown successfully.

Crankcase.—The front view of the engine at Fig. 471 clearly illustrates the general construction of the crankcase, which is all in one piece. There is an entire absence of joints which necessitate numerous bolts and nuts, with the result that the crankcase is exceptionally strong, light and clean. At the bottom, integrally cast, is the induction manifold, which by reason of its position, serves the dual purpose of heating the mixture and cooling the oil. Cast aluminum elbows make the connection between the inlet port and manifold. A simple and efficient rubber joint is fitted at the crankcase end of elbow which adjusts itself to any cylinder expansion.

Cylinders.—The cylinders are machined from solid steel bar with the fins formed integrally, and are perfectly symmetrical, great care being exercised in the finishing process. The cylinder heads are of cast iron, liberally finned. They are detachable, and have two valves of large diameter identical in size. The inside of the head and top of piston are of hemispherical shape, so forming a partial spherical combustion-chamber. Two sparking plugs are fitted to each head for duel ignition. It will be noticed that by simply removing the nuts of the cylinder foot studs and those fixing the induction pipe to the crankcase, the whole of the cylinder unit, complete with induction pipe, can be taken away in one piece as shown at Fig. 472 B so that in a few minutes the interior of the engine, piston, connecting rods, crankshaft, big end bearings, etc., can be exposed for inspection. The valves, which are of high tensile steel and interchangeable, are operated through the medium of rockers and tubular tappet rods, the rockers themselves being mounted upon hollow pins of ample dimensions containing a reservoir of oil.

Crankshaft, Connecting Rods and Pistons.—The crankshaft, a unit of vital importance, has received special attention, and the makers' experience, extending over many years, has proved the efficiency of this type. Machined from the solid out of a one piece high-tensile steel forging it is finished very short and stiff. It is designed to reduce the couple to a minimum, with the result that the engine is exceptionally steady at all speeds and free from vibration. The crankshaft assembly is shown at Fig. 472 A.

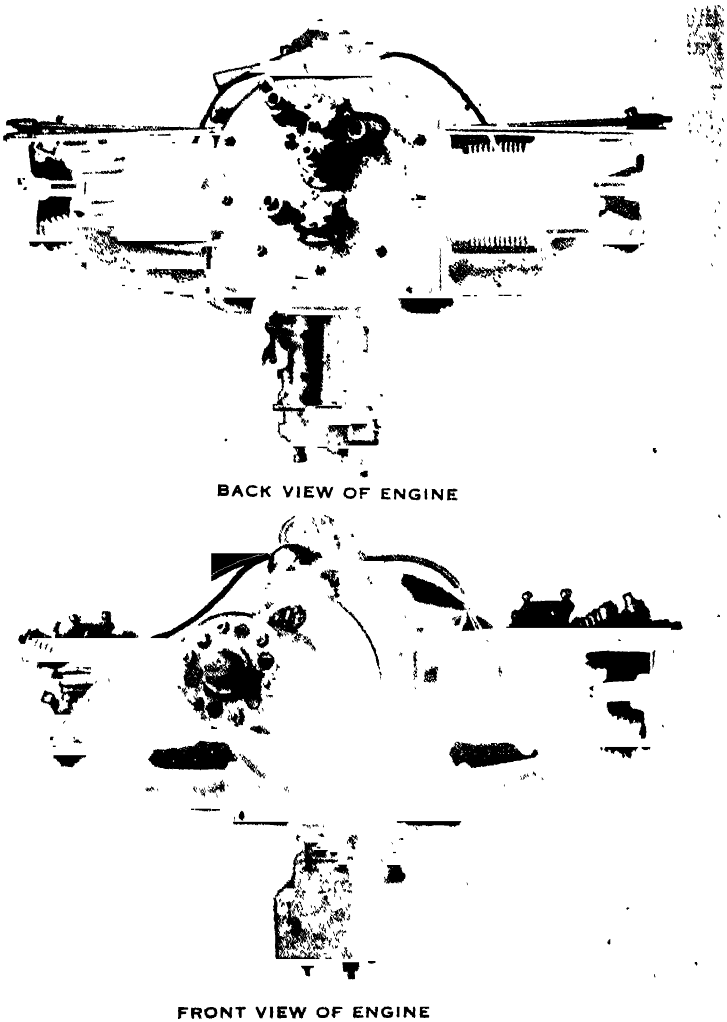
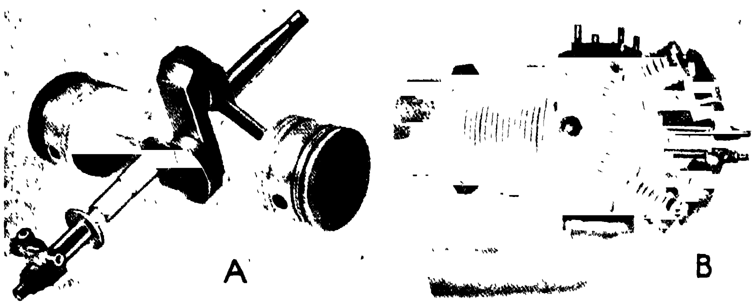


Fig. 471.—Views of ABC "Scorpion" Light Plane Engine, an Efficient and Popular British Design of the Flat Twin Type.

The connecting rods, though unusually light in construction, are also exceptionally strong, the complete rod being formed from a one piece forging of the same high grade steel as the crankshaft. The pistons are of aluminum alloy, fitted with two rings at the top only, the bottom one forming a scraper. The gudgeon pin is of generous dimensions, and is fixed to the connecting rod by means of a cotter bolt, nut, and split pin.

The big end bearings are of the plain, floating bush type. These bushes are of bronze and of patented design. They are split longitudinally, and each half is placed in position after the connecting rod has been threaded over the crankpin. The halves are joined by high-tensile steel screws which are locked by steel wire. The joint of these bushes is so arranged



CRANKSHAFT ASSEMBLY COMPLETE

CYLINDER UNIT COMPLETE

Fig. 472.—Crankshaft and Cylinder Unit of ABC "Scorpion" Engine.

that the full load does not tend to burst the joint, the screws being likewise relieved of this bursting load. Oil is fed to the big end under a pressure of 40 to 60 pounds by means of holes drilled through the crankshaft. All the other bearings are of the ball or roller type, and are of ample proportions. The thrust bearing is also of the ball type, and is located between two roller bearings at the forward end of crankshaft. This construction is clearly shown at Fig. 473.

Camshaft.—The camshaft, which is machined and finished with the cams integral, is very short and stiff, and having one exhaust and one inlet cam to serve two cylinders, synchronization of timing is easily obtained. Roller type tappets are fitted and slide in duplex plain bearings.

Lubrication.—Oiling is of the dry sump principle, there being both a pressure feed pump and a scavenging pump. These pumps are located on the rear cover of the crankcase, and are of the rotary type, simple in construction, efficient and dependable. The arrangement of these two pumps can be seen from the illustration showing the back of the engine. The connection for a revolution indicator is also fitted on the rear, and is to the Air Ministry standard, running at quarter engine speed. The oil is fed to the crankshaft by means of a plain bush which is located on the rear cover of the crankcase, and is easily detachable.

Ignition.—Ignition is provided by a B.T.H. magneto, of special design, fitted with impulse starter, and giving two sparks to each cylinder. The

magneto is inter-connected with the throttle and arranged so that full advance is effected at quarter throttle and over.

Carburetor.—The carburetor specially designed for this engine, is a Zenith double-choke triple-diffuser type, and is bolted directly to the crank-case. On the air intake is fitted an exhaust heater which is connected to the exhaust elbows by pipes with gas-tight joints.

The leading particulars of the engine are as follows:

Number of cylinders	2
Bore	4.015—102m/m
Stroke	3.6 in.—91/44 m/m
Capacity	1500 c.c.
Normal B.H.P.	34—actual 35
Normal Speed	2300 r.p.m.
High Power B.H.P.	38.3
High Power Speed	2550 r.p.m.
Maximum B.H.P. (for short bursts of five minutes)	40
Maximum Speed	2750 r.p m.
Petrol Consumption	.52 pts. B.H.P. hour
Fuel recommended-Mixture 80% Aviation, 20% Benzol—specific gravity	.768
Oil Consumption	.04 pts. B.H.P. hour
Oil recommended	Castrol R.
Oil Pressure—normal running	40-60 lbs.
Weight, complete with magneto, carburetor and propeller boss	109 lbs.

Remarks on Installation.—The engine may be fitted in a manner similar to radial mounting—direct to bulkhead—or fixed by means of brackets direct to longerons. Four ⅜-inch diameter reamed holes are provided for installation purposes. See installation drawings Figs. 474 and 475. The oil tank should be large enough to contain at least one quart of oil more than is required for the longest intended flight. This can be determined from the consumption, which is 1¼ pints per hour. The oil tank should be located as near as possible to the engine, above the pressure pump, so as to reduce skin friction in the pipe line, and at the same time reduce the lengths of oil pipes to a minimum.

All oil pipes should either be of flexible material or properly arranged to withstand vibration. The makers strongly advise use of flexible pipe. The main feed pipe to delivery pump should be at least ⅜-inch clear bore.

An oil cooler should be inter-connected between the crankcase and oil pump, and should be of such proportions that the oil temperature from the scavenger pump to tank does not exceed 50 degrees Centigrade. The approximate rate of oil circulating at normal speed is twelve gallons per hour. The oil gauge used should be capable of taking an overload up to 160 pounds per square inch, as in starting from cold the oil pressure will be high until the engine has warmed up.

A good deal of the efficiency depends on the suitability of propeller used. The makers supply a propeller which has given good results on both a monoplane and biplane, competing under conditions of utility and not purely speed purposes.

Instructions for First Run after Installation.—1. **Bolts and Nuts:**— Examine all bolts and nuts and see that they are quite tight and satisfac-

torily locked, especially those relating to any parts which might have been dismantled either for purposes of transit, or for facilitating installation.

2. Valve Clearances:—Examine clearances between valve and rocker, and, if necessary, adjust both inlet and exhaust to .010-inch when cold.

3. Magneto timing:—If magneto has been removed for any reason, this should be timed to fire 45 degrees when fully advanced. This timing is with the impulse starter inoperative, and to effect this the engine should be slowly turned over until the impulse starter is observed to snap, then

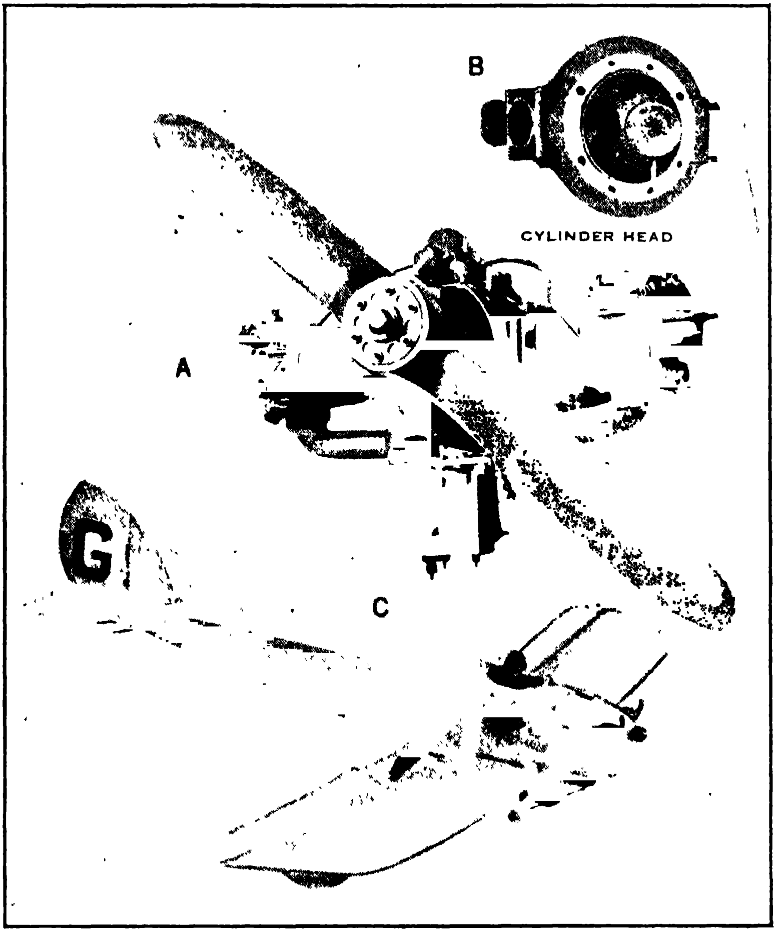


Fig. 473.—The "Scorpion" Engine and Propeller Ready for Installation in Light Plane is Shown at A. Interior View of Detachable Cylinder Head Shown at B. Practical Light Plane Suitable for "Scorpion" Powerplant Shown at C.

slowly reverse the engine until the cam is opening the contact breaker points. This is the true time of firing for speeds above slow running.

4. Controls:—Examine magneto and carburetor controls which are

interconnected. These are so arranged that at third throttle opening and over, the magneto is fully advanced and completely retarded when throttle is closed. See that both full throttle and closed throttle positions can be obtained.

5. Pipe Connections:—Make sure that all oil pipe connections are correct and that there are no air leaks on those pipes connected to oil pumps.

6. Valve Rockers:—Oil valve rockers by means of the oil gun provided with tool kit. Grease ball ends of tappet rods. Smear grease over tops of valve stems.

7. Starting Engine:—Turn propeller by hand (making sure first that ignition switch is off) until at least 60 pounds per square inch of oil pres-

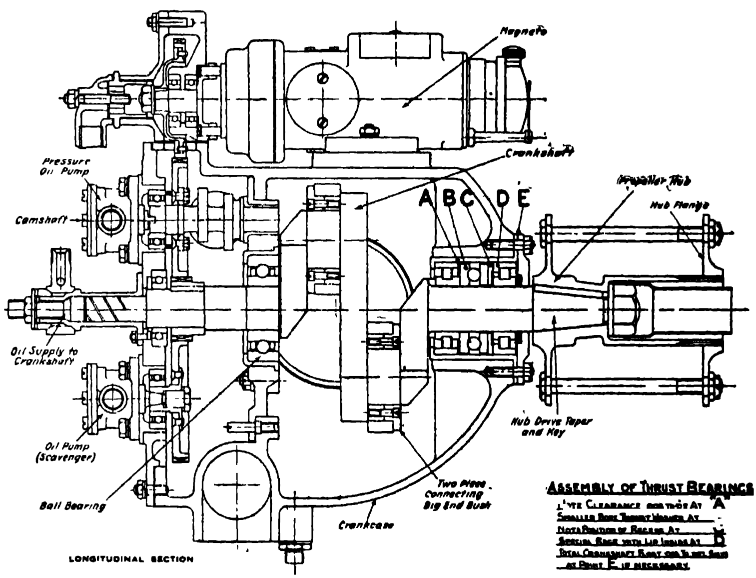


Fig. 473D.—Longitudinal Section of "Scorpion" Engine Showing Ball Bearings and Thrust Bearing Assembly.

sure is showing on oil indicator. This is a safe indication that connections are correct.

8. See that the wires to sparking plugs are suitably supported and that there is no danger of chafing through, or being burnt by contact with some part of the cylinder or head.

9. Engine should now be ready for starting. To facilitate starting first of all flood carburetor and then suck in a good charge on full throttle, with air intake restricted. Close throttle and after switching on ignition the engine should start with first pull.

10. Oil Pressure:—Let engine idle for three minutes to allow oil to circulate, and watch oil indicator which will probably read about 90 pounds per square inch, with the oil cold. Open up engine to about 1,600 r.p.m., and allow to get properly warmed up. When thoroughly warm

the oil pressure should be about 60 pounds per square inch, and should never be allowed to fall below 40 pounds per square inch. Oil pressure is controlled by a release valve on oil distributor on rear of engine, which is properly adjusted before engine leaves the factory, but should the pressure be affected by the type of oil used, adjustment can be effected. Oil recommended is Castrol R in summer, Castrol C in winter, or pure Pharmaceutical Castor Oil. Castrol is a mixture of mineral and castor oils.

11. Running Engine:—When engine is thoroughly warmed up and everything is satisfactory, the engine may be slowly run up to full throttle to check the stability of mounting, etc. However, full throttle running on the ground should not exceed three minutes duration, as it must be remembered that the engine is not receiving its normal cooling until it is in actual flight.

12. Stopping Engine:—Shut down the engine in the following manner:—Close throttle to slow running position and allow to idle for two minutes, then switch off or slow right down and turn off fuel, and allow engine to stop through lack of gasoline.

13. Examination After Running:—After shutting down examine the engine all over as follows:

a. There should be no oil or fuel leaks, and all joints should be tight.
b. The cylinders will be quite hot, and all securing nuts should be tight and also cylinder head bolts should be tight.
c. There should be no shake in the propeller hub, and all hub bolts should be tight.
d. The lubrication system should be completely drained, and all filters cleaned and replaced, and tank refilled with fresh oil.

14. Carburetion:—All engines are tested on a standard test propeller, and the jet settings in the carburetor sent with the engine are those which secured smooth running at all speeds during test. The throttle is adjusted to give slow running at about 800 r.p.m. It is inadvisable to set the adjustment below this speed, as this is a very sensitive position of the throttle, and should the adjustment be set much lower there is a possibility of the engine stopping when closing the throttle quickly. It is possible, however, owing to the different conditions, when the engine is installed in the machine, that some variation in the settings may be necessary, to obtain satisfactory running. In such cases the makers are always prepared to exchange carburetor jets for others giving a richer or weaker mixture if required, or alternatively, Zeniths, the makers of the carburetor, who have depots in most countries, will, on request supply any parts or give any advice or assistance that is possible.

Instructions for Daily Inspection and Running of Engine in Flight.— Follow previous instructions as given under heading (First Run After Installation). Also see that impulse starter is in operation, by noticing that there is a click when the propeller is pulled over slowly. If no click is heard, probably the pawl is sticking. This can be eased by washing out through the small hole with kerosene and, when dry, lubricating with very thin oil.

2. Check contact breakers of magneto to see that they are free. Apart from this, the magneto requires very little attention. Full instructions as

to the functioning of this unit can be obtained from the separate booklet issued by the makers—The British Thomson Houston Co., Ltd.

3. Periodically examine platinum points to see that they are clean and smooth, and opening correctly.

When in Flight.—

4. a. Oil Pressure:—See that oil pressure never falls below 40 pounds to the square inch.
   b. Engine Speeds:—The normal speed of engine is 2,300 r.p.m. and engine may be run indefinitely at this speed. A high speed of 2,500 r.p.m. is permissible for periods of one hour, and a maximum speed of 2,750 r.p.m. for a short burst only of five minutes duration.
   c. Violent acceleration of engine is to be avoided.
   d. Altitude Controls:—The altitude control should be used with discretion, as a weak mixture is to be avoided. If altitude lever is not so connected that it automatically closes with the throttle make sure that it is closed before throttling down.
   e. Oil Temperature:—Oil temperature should never exceed 60 degrees Centigrade, and should normally be 40 degrees Centigrade.

After Landing from Day's Flying.—

5. Examination:
   a. Examine all over for oil leaks, fuel leaks, etc.
   b. Check oil and fuel consumption.
   c. When everything has cooled off, turn engine over and by feel and hearing be assured everything is correct.
   d. See notes Section 13 under heading "First Run after Installation."

Instructions for Top Overhaul.—It is advised that a top overhaul should be undertaken after every 50 hours running. All parts connected with the cylinders and rocker gear should be dismantled, thoroughly examined and cleaned. Replacements should be made where necessary. It should not be necessary to remove the engine for this overhaul.

The tool kit, as supplied with the engine should be used for this purpose, as the use of proper spanners avoids damage to nuts, bolts, etc. And for the same reason it is not good practice to use an adjustable spanner except in cases of emergency. When dismantling it is advisable to temporarily replace nuts and bolts in their respective positions to avoid loss and confusion. A number of the parts are marked by dots or figures and indicate the positions of such parts. Care should be taken to replace such parts according to the marks. Split pins should not be re-used, and spring washers that have lost their life should be replaced.

Removing Cylinder Unit.—For removing cylinder unit for internal inspection proceed as follows:

1. Remove high tension leads from plugs.

2. Remove tappet rods. Take care that piston is down the stroke, and that the valve is in shut position before levering the rocker for removal of any one particular tappet rod.

3. Remove exhaust connections to exhaust elbows and heater muff.

4. Remove nuts holding plates on bottom of induction pipes, and slip back plates and rubber washers.

5. Remove cylinder foot nuts and washers.

6. Cylinders may now be removed. This is done by gently rocking the cylinder up and down, by hand, and at the same time exerting a pull. There are long spigots to the cylinders. No undue force should be necessary.

7. As each cylinder is removed, support each piston by a clean small piece of wood to protect pistons against damage. Always be careful in turning the engine with cylinders removed.

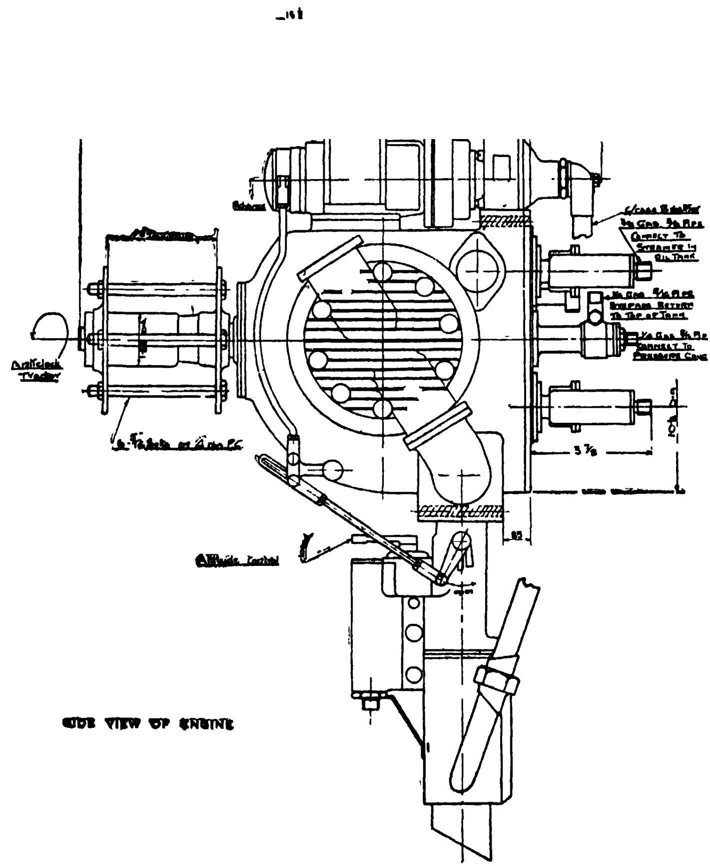


Fig. 474.—Drawing Showing Side View of ABC "Scorpion" Engine Giving Principal Dimensions.

8. Most of the interior of the engine is now exposed, and a superficial examination of the interior can now be made. See that bronze brushes on big ends turn freely both on crankpin and in connecting rod. These are "floating" bushings and must be free, yet not unduly loose on either the crankpin or in connecting-rod big end.

Dismantling Cylinder Unit.—For dismantling cylinder units:

9. The rockers should now be removed from cylinders and it is better to place these parts so that they can be re-erected in their respective positions.

10. The valves can now be removed, and for this purpose, it is best to make a block of wood which will be a loose fit in cylinder, and will also be slightly domed on the top. The length should be about one-quarter-inch longer than the cylinder. Hold the cylinder lightly in a vice across the flats of cylinder feet, and with the block of wood resting on the bottom of vice, the valve springs can become pressed, and split collars removed from valves. For levering the valve springs replace the rocker pin and use this as a fulcrum. It is most advisable to keep the valve split collars together with the valves to which they belong.

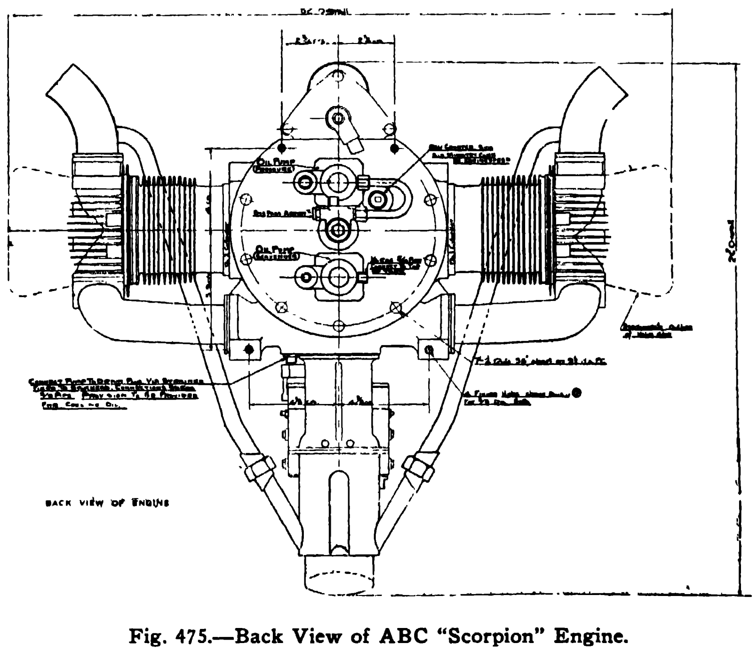


Fig. 475.—Back View of ABC "Scorpion" Engine.

11. It should not be necessary to remove cylinder head, but if for any good reason this is done, a new joint washer must be used.

12. It should not be necessary to remove pistons but if for any good reason these are to be removed first of all withdraw gudgeon bolt and then gudgeon pin can be easily pushed through piston and connecting rod small end. Keep respective bolts, nuts, gudgeon pins and pistons together.

13. Decarbonize cylinders and valves, and grind in valves.

14. Remove rings from piston. Decarbonize all over, clean thoroughly and replace rings.

15. Check valve spring tension, which should be not less than:

Inner:—45 pounds when compressed to 1.4 inches long.

Outer:—40 pounds when compressed to 1.3 inches long.

Replace any that are bad.

Re-Assembly of Cylinder Unit and Pistons.

16. Re-assemble the parts following the above instructions in the reverse order. The rubber rings on induction pipes should be renewed, and remember to slip both the plate and rubber ring over induction pipe before putting cylinder into position.

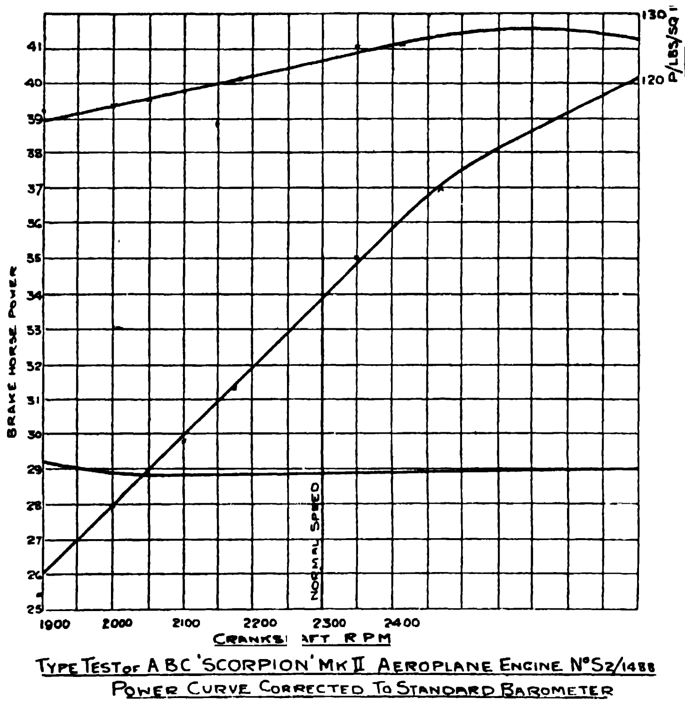


Fig. 476.—Horsepower at Various Crankshaft R.P.M. of ABC "Scorpion" Mark II Airplane Engine.

17. Special attention is called to the tightening up of wristpin bolts. These should only be pulled up so as to be in slight tension. Excessive tightening is liable to over stress the bolt.

18. When the foregoing units are re-assembled the engine will be ready for running, when the instructions under heading (Instruction for First Run after Installation) should again be observed.

Instructions for Complete Overhaul.—It is recommended that the engine should be removed from machine for complete overhaul after about 150 hours running.

Special extractor tools are necessary for complete dismantling, and if these tools and the proper facilities are not available for this work, it is

advised to return the engine to the makers for overhaul. If the necessary arrangements can be made for overhaul, and competent mechanics are available, the overhaul can be done by adhering to the following instructions. The special tools required can be supplied, and their use is indicated in the following instructions:

Dismantling Engine:

1. Remove propeller hub and propeller by means of extractor tool supplied with the standard tool kit. Of course this will be done before the engine is detached from the machine.
2. Carry out the operations enumerated under heading (Top Overhaul), Nos. 1 to 15 inclusive.
3. Remove pistons. Place wristpins, bolts, etc., with each piston.
4. Remove carburetor and controls
5. Remove magneto.
6. Remove tappets complete with guides.
7. Remove pressure pump (Top pump).
8. Rear cover may now be removed as one unit. This unit can be further dismantled if considered necessary.
9. The inner cover is now exposed, and the nuts should be removed from studs holding cover in position Remove washers from studs.
10. Now remove nose bearing cover with its felt washer and protecting washer.
11. The crankshaft unit, together with inner cover and bearing, may now be removed, and should be done in the following manner.

Attach special extractor tool to the nose housing studs, using all six studs.

Fold connecting rods so that they are inside of the crankcase. Get a second person to guide the connecting rods and crankshaft through the slots in crankcase. By carefully screwing up the extractor bolt the crankshaft may be pushed out of position. It may possibly happen that crankshaft will tend to turn, and this can best be prevented by replacing a bar across the inside of the cylinder ports and under the middle web of the crankshaft. During this operation frequently make sure that everything is clear and nothing is being unduly strained.

12. The inner cover, together with ball race housing, should now be removed from crankshaft. If this should require tapping off, be careful to tap off through the medium of the housing, so as not to disturb the fit of the housing in cover.
13. Remove the crankshaft timing wheel with small "U" shaped extractor tool.
14. The large ball bearing may now be removed by using the large "U" shaped extractor tool.
15. The inner race that is left on the nose end of the crankshaft need not be removed, unless it is necessary to be replaced.
16. Now remove the big end bushes in the following manner: Draw out the locking wires which cannot again be used. Remove screws with a good screwdriver that is a close fit in slots. Place screws so that they may be replaced in their original positions. Turn bush until larger half is central to the top dead center of big end pin, and gently draw sideways away from

connecting rod. Repeat this operation with the remaining half then immediately join the halves together, putting the screws in their respective positions. The connecting rods may now be removed from the crankshaft. Note.—The small end of connecting rod is offset, and the position of this should be noted so that they can be re-erected correctly.

Clearances or Tolerances Allowed.—Having completely dismantled the engine, all parts should be thoroughly cleansed in gasoline or kerosene and protected from damage and dirt. An examination of all parts may now be made, and below is a list of original clearances, or tolerances, allowed in Scorpion engines. All clearances given are slack. Where tight fits are required these are marked "T."

Crankshaft	Original	Maximum
Big end pins out of round	.00025	.002
Big end bush on crankpin	.0025 to .003	.005
Total float of bush and connecting rod	.004	.01
Roller bearings on nose end	Light drive	—
Ball bearings on tail end	"	—

N.B.—If big end pins are badly worn out of round, or scored, they can be re-ground if returned to makers. New bushes will be supplied and for this purpose it is necessary to return connecting rod so that correct fit can be obtained both for fit in connecting rod and end float.

Big End Bush	Original	Maximum
For clearance to pin and float see crankshaft.		
Clearance in connecting rod	0035-0004	.006

N.B.—If new bushes are required send exact size of pin and bore of connecting rod, so that correct fit can be given. Bushes will be made full in length for fitting.

Connecting Rod	Original	Maximum
For fit to big end bush and float, see under crankshaft and big end bush.		
Fit of gudgeon pin	Tapping fit	Tapping fit

N.B.—Connecting rods, if badly worn, may be re-ground and oversize bushes supplied. It is necessary to send the crankshaft to the rebuilder as well so that correct fits may be given.

Cylinder	Original	Maximum
Piston fit to cylinder:		
2nd land	.0185	.026
Skirt	.0135	.019
Out of round	.00025	.004

N.B.—These clearances are taken with piston at top of its working position. Cylinders may be reground up to .01 oversize and new pistons fitted.

Piston	Original	Maximum
For fit to cylinder, see under cylinder.		
Fit of gudgeon pin in piston	Push fit	.001
Fit of piston ring to piston	.004	.007

Piston Ring		
Gap	.005	.01

Cylinder Head

	Original	Maximum
Exhaust valve guide fit to head	T.	—
Fit of exhaust valve to guide	.007	.012
Inlet valve guides fit to head	T.	—
Fit of inlet valves to guide	.003	.006

Valve Springs

Inner. When compressed to 1.4-inch long	55 lbs.	45 lbs.
Outer. When compressed to 1.3-inch long	48 lbs.	40 lbs.

Rockers

Fit of bush to rocker	T.	—
Fit of bush to pin	.0015	.003
Fit of pin to rocker support	Light drive	—

Re-Assembly after Overhaul.—

1. Any new parts that have to be fitted should be trial fitted first before proceeding with final assembly.

2. Re-assemble the engine in the reverse order of dismantling. Special attention is drawn to the following points, more or less in the order of which they arise, and reference should be made to illustration of section through engine at Fig. 473 D:

a. It will be found that parts relating to each big end and connecting rod, are numbered 1 and 2, or by dots, so that respective rods and big end bearings may be correctly replaced on original big end pins. The big end pin nearest propeller being known as No. 1.

b. Make sure connecting rods are assembled to crankshaft with offset of small end of connecting rods correctly positioned. Offset of each small end should be towards center web of crankshaft.

c. Use $\frac{1}{16}$-inch mild steel wire for locking big end bearing screws. Be sure to use same screws in the original positions. These should be taken up tightly with a properly fitting screwdriver, and if screws have been kept in proper position, the slots will line up with the holes for locking wires. If for any unseen accident the screws have become mixed or mislaid, the slots are lined up by trial, and by easing the bottoms of counter-sinks until the correct position and tension is obtained. In turning over the ends of the wire, be careful not to spread the slots, thereby taking up the side clearance.

d. Attention is called to the clearances between bearings and thrust washers, as shown on section drawing. See that races and washers are correctly positioned. Crankshaft should turn freely when all bearings are in position.

e. The camshaft timing is easily obtained by placing the crankshaft with keyways towards top of engine, and the tooth marked "O" should be inserted in the gap of timing wheel directly above the keyway.

f. Leave off the top oil pump until the cover is fitted, as it is possible to see the revolution counter wheels enter into mesh when pushing cover home.

g. Refer to note seventeen under heading "Instructions for Top Overhaul" before replacing pistons.
h. Refer to note sixteen under same heading as above before putting cylinders into position.
i. Refer to note three under heading "Instructions for First Run after Installation" for timing of magneto.
k. The correct position of oil pump covers is marked by a groove on edge of cover and top edge of pump. These should be in line. This can be checked as follows: The offset of spindle on cover should be placed so that the offset is towards and in line with the top right hand screw hole when facing the top of pump.

When the engine is assembled and installed in machine, follow all the instructions under heading "Instructions for First Run after Installation."

The A. B. C. "Hornet" Engine.—A light plane engine of distinctly novel type has recently been produced by A. B. C. Motors, Ltd., of Walton-on-

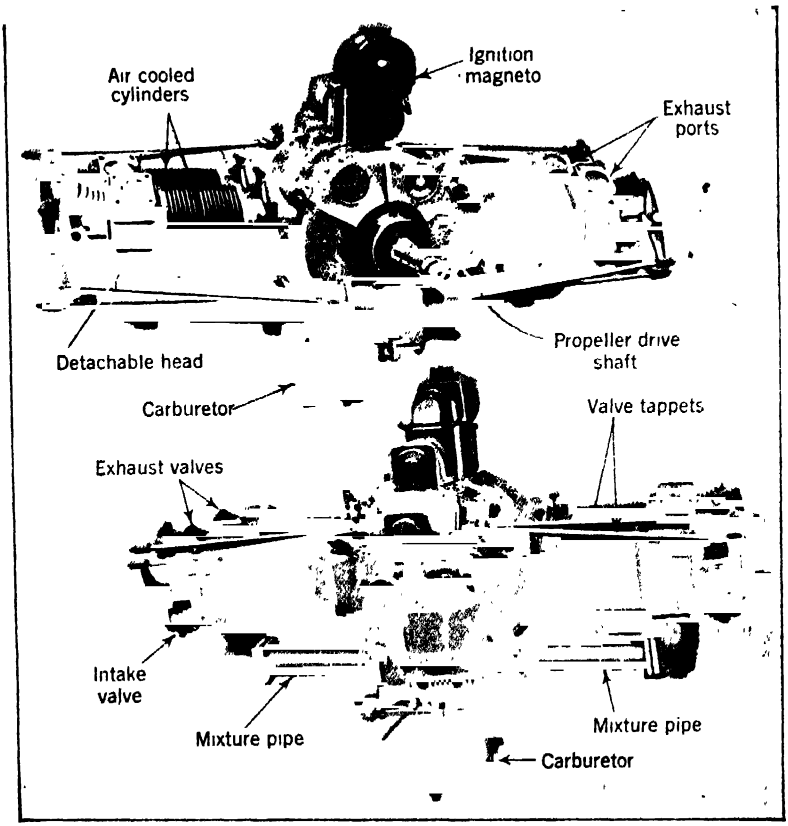


Fig. 476A.—Three-Quarter Front and Rear Views of the A.B.C. "Flat Twin" Type Hornet Four-Cylinder Engine. Note Small Frontal Area Possible with This Construction. Valve Operating Mechanism Placed at Front and Rear of Engine Actuates Nearest Valves.

Thames, England. Known as the "Hornet," the new engine may be said to be a development of the smaller type (the "Scorpion") which the writer has just described and which this firm has had in production for some years, and of which considerable numbers are in use on the Continent, especially in Germany. Like the "Scorpion," the "Hornet" is an air-cooled "flat twin," but with the difference that it has four cylinders instead of two. By retaining the "flat twin" arrangement, an engine of very low frontal area has resulted, and the mechanical balance of the new engine is excellent.

Its compactness is clearly shown at Fig. 476 A. The aluminum crankcase is of cylindrical shape, and is in three pieces, the joints being vertical, and in line with the cylinders, spigoted and fastened by bolts and nuts. At the bases

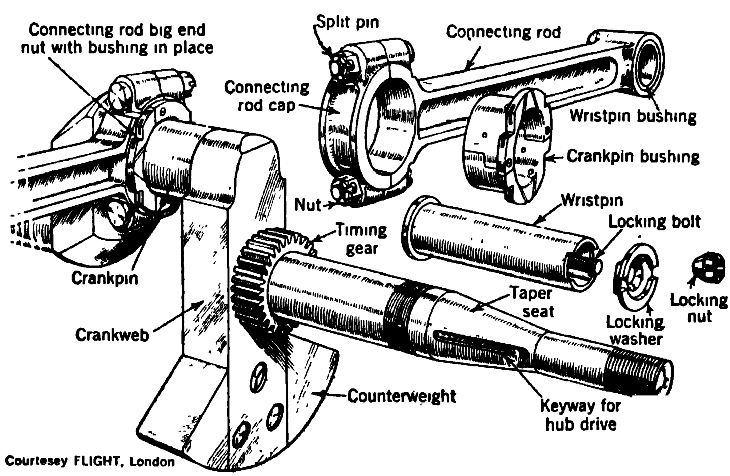


Fig. 476B.—Some Constructional Details Showing Front Portion of Hornet Crankshaft with Special Floating Bush Big End Construction Outlined. Note Also Wristpin Construction Showing Locking Arrangement.

of the cylinders are four long bolts, two on each side, which run right through the crankcase from front to back and serve for mounting the engine in the aircraft. If desired, it is possible to support the front of the engine from the forward ends of the bolts, as well as from the rear end, but the crankcase is very sturdy and rigid, and probably it will be quite satisfactory to mount the engine from the back only by a plate attached to the rear end of the four mounting bolts.

The front cover of the crankcase houses the short camshaft which operates the valves of the front cylinders, and also the front journal roller bearings and the double thrust ball race. The rear cover contains the two oil pumps, which are formed as a unit, the tachometer drive, and the camshaft for the rear cylinders. The crankshaft is of the two-throw type, each pin being long enough to accommodate two big-ends side by side. It is carried in three bearings, of which the front and rear journal bearings are of the roller type, while the center bearing is a plain phosphor bronze bush, split and supported in a circular plate.

The cylinders are of heat-treated steel, machined from solid, while the cylinder heads are of cast-iron. * Incidentally, the cylinder heads are identical with those of the A. B. C. "Scorpion," Mark II, as are also the pistons and certain other parts, so that users of both types of engine have here an advantage in the smaller number of spares which it is necessary to stock. There are two valves per cylinder, operated by push-rods and rockers from the two

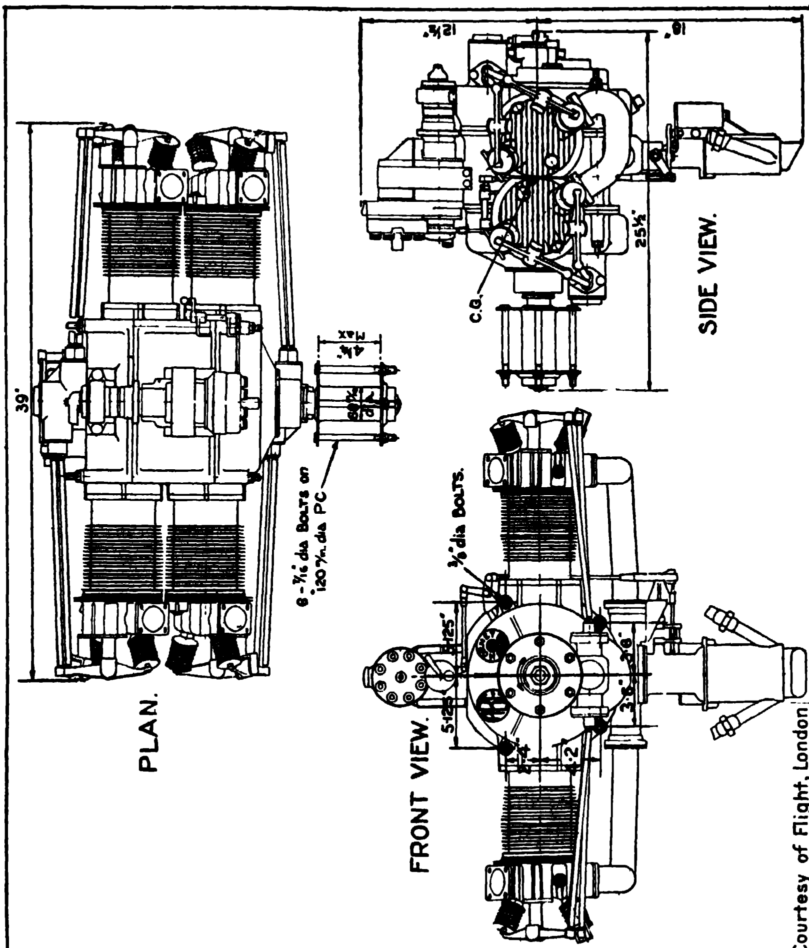


Fig. 476C.—Three View Drawing of the A.B.C. Four-Cylinder Air-Cooled Hornet Engine Showing Main Dimensions Necessary for Installation in Airplanes.

camshafts on front and back of the engine. As the engine is provided with dual ignition (Watford dual-spark magneto), there are two sparking plugs per cylinder. Aluminum alloy pistons are used (identical and interchangeable with those of the "Scorpion"), fitted with fully floating gudgeon pins. The connecting rods are of H section, and the big-ends have plain, fully floating phosphor-bronze bearings, details of these being shown at Fig. 476 B. Both the big-end bearings and the center bearing are force feed lubricated.

The back cover of the engine houses the two oil pumps (pressure and scavenger), which are of the eccentric-operated plunger type, and of equal design and capacity. Provision is also made for fitting a fuel pump if desired, although in most instances direct gravity feed will probably be employed. The induction system is of very simple type, the manifold being cast integral with the central portion of the crankcase and thus the fuel mixture is heated and the oil cooled at the same time. From the central manifold under the crankcase pipes are taken to each side, with forked pipes conducting the mixture to the separate cylinders.

SPECIFICATIONS

Following are the main data relating to the A.B.C. "Hornet":

Cylinder bore	4.015 in. (102 mm.)
Cylinder stroke	4.8 in. (122 mm.)
Cubic capacity	243 cu. in. (3,990 c.c.)
Normal power	75 b.hp.
Maximum power	82 b.hp.
Normal speed	1,875 r p.m.
Gasoline consumption (80% aviation spirit, 20% benzol)	0.53 pts./b.hp./hour
Oil consumption	0.035 pts./b.hp./hour
Starting	Impulse starter fitted
Weight of engine complete	225 lb. (102.2 kg.)
Specific weight (on normal power)	3 lb./hp. (1.36 kg./hp.)

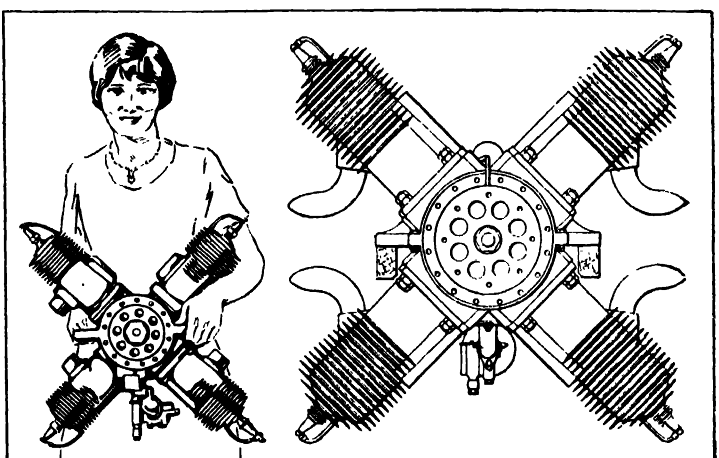


Fig. 477.—Meteormotor Radial Air-Cooled Engine is a Four-Cylinder Two-Cycle Type of Distinctive Design. View at Left Shows Small Size and Light Weight of this Engine.

The Meteormotor Radial Engine.—This light four-cylinder X-type motor was developed primarily for use in the Meteorplane, a light, sport type that had flown with various motorcycle engines. When powered with the motor illustrated at Figs. 477 and 478, the maximum speed of the plane was increased to 90 miles per hour and the ceiling to 15,000 feet. The latest model has copper cooling fins instead of integrally cast iron flanges. The engine operates on the two-cycle principle. The cylinders are made of the

finest grain gray iron, machined both inside and outside, and ground. By a special process, the copper cooling fins are electrically united to the cylinders. The crankshaft is of special heat treated chrome-vanadium steel, machined and ground from a solid 90 pound piece and, when finished, weighs only 6½ pounds. The crankcase is of silicon-aluminum and, for ease in installing, it is fitted with four mounting brackets. Special tubular connecting rods are used in the engine, with steel backed babbitt bearings. The pistons are of fine grain cast iron and carry three rings and weigh but ten ounces. The valves are of large size and made of tungsten-steel with

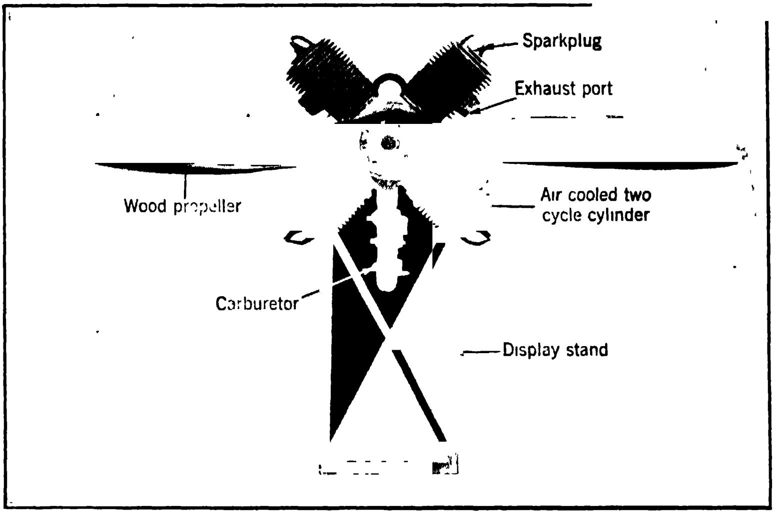


Fig. 478.—Model 79 Irwin Twenty Horsepower Radial Air-Cooled Engine which Weighs About 60 Pounds, Without Propeller and Hub.

bronze stems. Both the main and thrust bearings have $^{13}/_{16}$-inch diameter balls. A special Winfield carburetor is used, and a high tension Bosch magneto furnishes the ignition. Lubrication is by pressure and can be regulated from the dash in the pilot's cockpit of a plane fitted with this engine. The complete weight of the Meteormotor, including carburetor, magneto and propeller hub, is only 60 pounds. The cylinder capacity is 79 cubic inches. The engine, which is very smooth in running, develops twenty horsepower, at 2,000 r.p.m., and consumes 1½ gallons of gasoline per hour and ½ pint of lubricating oil. The simplicity of the engine is evident from the illustrations. It will be seen that, contrary to usual practice with radial engines, the engine bearers are not arranged to attach onto a circular casting, but hold the engine down by means of two flanges attached direct to two longerons. This makes for simple installation.

The Szekely SR3.—The O. E. Szekely Corp. of Holland, Mich., has been consulting and industrial engineers to various manufacturers for a number of years and as a result of the experience gained in this work, it reached the conclusion about a year ago that there would be an ever increasing sale for simple, light weight, reliable, air-cooled aircraft engines, em-

bodying many of the exclusive features which have worked out so well on equipment it has designed for others. Accordingly it undertook the design of a three-cylinder, radial, air-cooled engine for light aircraft, to be followed in the near future by a five-cylinder, using practically all of the

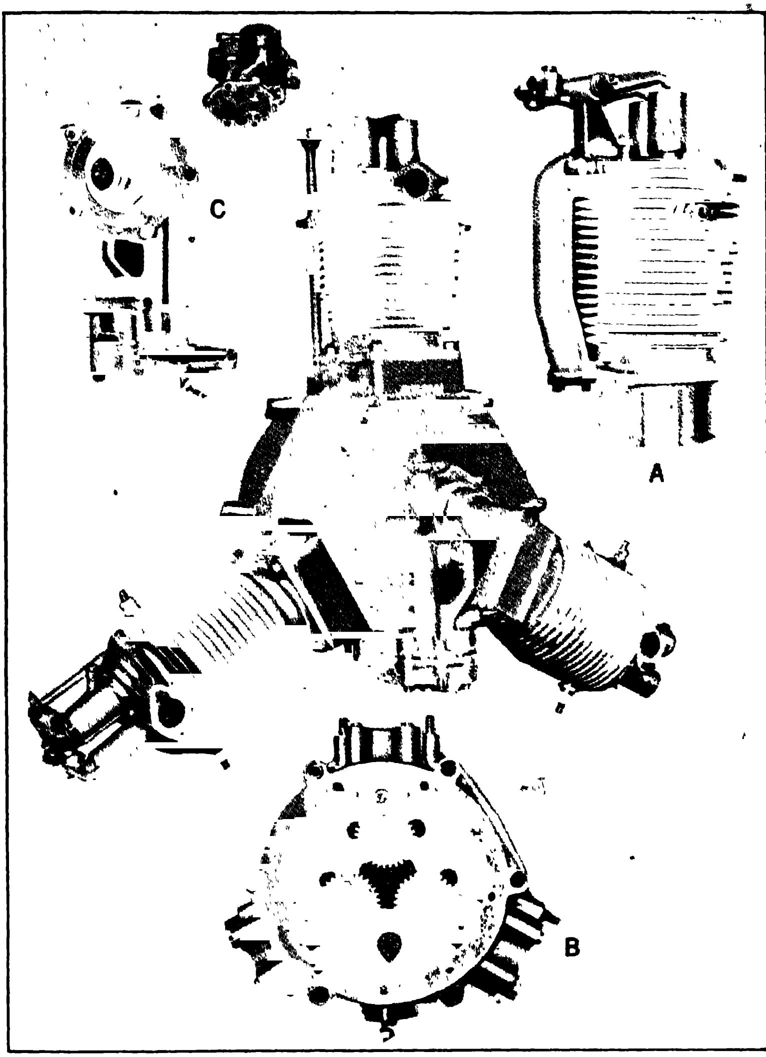


Fig. 479.—Szekely Three-Cylinder Engine and Some of its Principal Parts. A—Cylinder Assembly. B—Timing Gears and Cams, Showing Tappet Actuators. C—Oil Pump Unit.

parts of the three-cylinder engine.

The extremely simple outward appearance of the three-cylinder design as shown at Fig. 479 commends it to approval for the only visible moving

parts are the push rods and rocker arms, all remaining parts being entirely closed. The engine has a $4\frac{1}{8}$-inch bore by $4\frac{3}{6}$-inch stroke, giving a total piston displacement of 190 cubic inches. Operating at its rated speed of 1,800 r.p.m., 40 horsepower is guaranteed; as a matter of fact, actual brake tests are said to show that this engine develops over 42 horsepower. The compression ratio is 4.8:1. The mounting flange for the engine consists of a round machined pilot fitted into the engine bracket on the plane. The engine is held in place by six tie rods, each of which passes entirely through the engine, so that the front cover, crankcase, rear cover, and mounting bracket are securely locked together as shown in installation drawings at Fig. 481.

The cylinders which are shown at Fig. 479 A are chrome nickel gray iron, with cylinder head cast integral and are held to the crankcase by four studs. Each cylinder has a skirt or piston guide extending approximately $2\frac{1}{2}$-inches into the crankcase. Intake and exhaust passages are scraped and sand blasted and the entire cylinder is provided with numerous thin fins to provide ample radiation for the air cooling. Valve seats are part of the cylinder and are a 45 degrees angle. Two valves are used in each cylinder, these being silchrome steel, mushroom type, 45 degrees seat, providing a clear gas flow area of $2\frac{1}{2}$ square inches. The valves are $1\frac{13}{16}$-inches diameter by $\frac{11}{32}$-inch lift. The valves are actuated from the cam through hollow push rods with hardened ends and bronze bushed drop forged rockers. Tappet adjusting screw is placed in the rocker and locked in position, after adjustment, by a cap screw.

The lubricating system is interesting. A double type gear pump is driven by a bronze spiral gear directly from the crankshaft as shown at Fig. 479 C. Four spur gears are used in the pump itself, the upper set receiving oil through a $\frac{3}{8}$-inch line from an oil tank in the plane and delivering it, under pressure, to the connecting rod bearings and, by splash, to the main bearings, gears, and cylinder walls. Two other gears form the scavenging pump and are slightly larger than those of the delivery pump. This picks up the oil from the lower part of the case, to which the surplus runs, and delivers it through a $\frac{3}{8}$-inch line to the oil tank. An interesting innovation from usual practice is that the oil relief valve and the take off for oil gauge are placed at the rear of the engine so that oil pressure reading is taken after the oil has passed entirely through the engine. The pressure at the pump is approximately six times the reading given at the rear of the engine. This is said to be an additional safeguard, as it shows the flier that each part of his engine is receiving sufficient lubrication as long as oil pressure shows on the gauge. A gauge pressure of four pounds per square inch to ten pounds per square inch is recommended, which means the pump pressure usually noted on other engines is 40 pounds per square inch to 60 pounds per square inch.

The crankcase is of aluminum alloy, with front and rear covers of the same material. These covers hold the main bearings. The main crankshaft bearings as shown at A, Fig. 480 are of the roller bearing type and located as close to the center of the crankpin as it is possible to get them, thus reducing vibration to the minimum. The intake manifold is cast as an integral part of the crankcase, in the form of a circular chamber with

opening flange for carburetor at the bottom of the engine as at C, Fig. 480. Three outlets from this circular chamber are connected to the cylinder by an individual aluminum intake manifold, which fastens to each cylinder and is packed in such manner with gasket at the crankcase that expansion and contraction may occur without putting a strain on any part of the engine and without permitting air leaks.

The crankshaft itself is 3140 S.A.E. material, having a diameter of 1 $^{37}/_{64}$ inches. The connecting-rod bearing on the crankshaft is 1 $^{7}/_{16}$ inches by 2 inches. The crankshaft is a single piece drop forging, to which counter-weights are added to insure perfect balance of the engine itself.

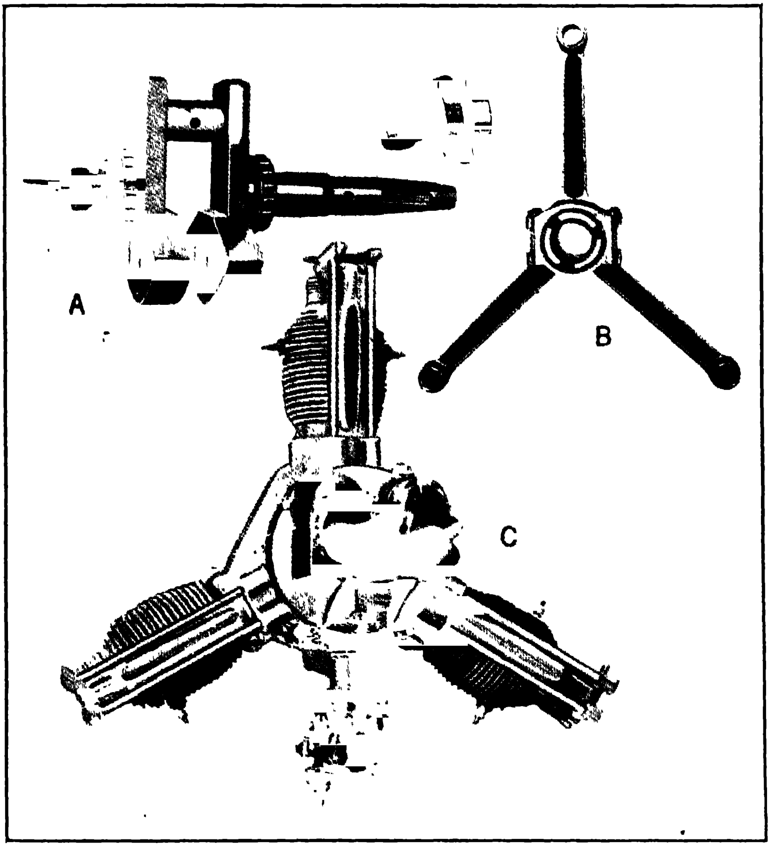


Fig. 480A.—Crankshaft Assembly of Szekely Engine. B—Connecting Rod Assembly. C—Rear View Showing Magneto Installation.

The propeller thrust bearings is an S.K.F. bearing of the deep groove, radial ball bearing type and is taken directly between the front of the crankshaft and the front gear cover of the engine itself. The propeller hub is steel and heat treated for maximum strength. Each propeller hub is lapped to the crankshaft of its own engine, in addition to the precision operation of grinding both the hub and the crankshaft.

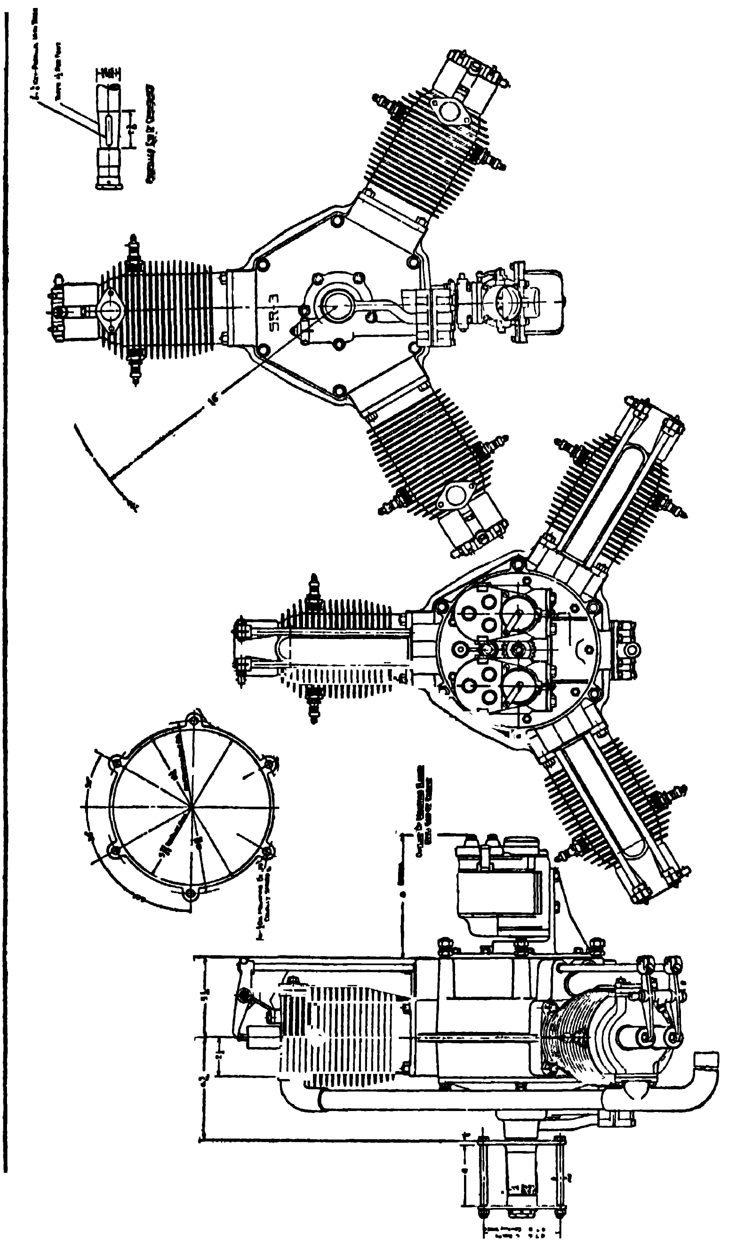


Fig. 481.—Installation Drawing of Szekely Airplane Engine.

Connecting-rod assemblies shown at B, Fig. 480, are drop forgings, heat treated for toughness and machined all-over. The upper end of the connecting rod is bronze bushed. The lower bearings are sections of a cylinder cut on an angle with the axis of the bearing and contact with a bronze bearing, the internal portion of which is babbitt lined and free to revolve around the crankpin. Oil pressure is delivered to the main connecting-rod bearing and to each individual connecting-rod bearing. This connecting-rod assembly is said to provide greater insurance of complete lubrication and larger bearing surfaces in proportion to the load placed upon them than conventional practice of a master rod with round pin rods operating from it.

The pistons are of aluminum alloy, solid skirt type, each equipped with three ⅛-inch piston rings. The piston pin is hollow, hardened and ground and bears in piston bosses in the aluminum piston at either side, but is of the full floating type, in that it is free to turn both in the piston and in the connecting-rod bearing.

The cam arrangement shown at B, Fig. 479 is interesting and, while novel, has been used in other services for a number of years by the Szekely organization, so that nothing untried is being used in this respect. There is but one cam to operate both the intake and exhaust valve on each cylinder. This cam is driven from a spur gear on the crankshaft and operates the valve through the means of a hardened and ground cam follower, which is bronze bushed and located by means of a hardened and ground pin fastened to the crankcase.

The ignition system consists of two Robert Bosch magnetos mounted on a shelf which is an integral part of the rear cover as shown at C, Fig. 480, and driven from the engine by means of spur gears. Each magneto fires a sparkplug on each of the three cylinders, so that the engine is provided with two independent ignition sources. The carburetor is suspended below the engine and connected to the crankcase by a venturi type manifold. It is the Zenith 1½ inch balanced airplane type. The weight of the engine, with all accessories, is guaranteed by the manufacturer not to exceed 153 pounds. The average production engine weighs approximately 148 pounds. Tests have demonstrated that this engine is ideal for a single or two place plane having from 25 to 30 feet wing span and weighing between 475 and 525 pounds. As installed in such a plane, the engine turns a 40 horsepower propeller at 1,725 r.p.m. on the ground and better than 1,850 in the air, in this way giving an ideal cruising speed of from 80 to 85 m.p.h., at an engine speed of from 1,550 to 1,600 r.p.m. Flight tests show that the fuel consumption, under average conditions, is approximately .58 pounds per horsepower hour, with an oil consumption guaranteed not to exceed .029 pounds per horsepower hour.

QUESTIONS FOR REVIEW

1. What type of Motorcycle engine can be used for sport planes?
2. Describe typical "flat twin" airplane engines.
3. What is an important feature of the Mercedes-Benz engine for light planes?
4. Describe the Bristol "Cherub" engine.
5. Outline Construction of A.B.C. "Scorpion" engine.

CHAPTER XXIX

MEDIUM POWERED AIR-COOLED ENGINES

The American "Scorpion"—The Dayton "Bear" Engine—Le Blond Aviation Engine—The Warner "Scarab" Engine—The Super Rhone Engine—Velie Aircraft Engine—Anzani Aviation Motors—Cylinders and Crankcase—Pistons—Valves and Rocker Arms—Inlet Manifold—Connecting Rods—Crankshaft—Distribution—Timing Anzani Engine—Anzani Engine Care and Operation—To Stop Engine—Standard Anzani Adjustments—Preparation to Start Engine—Starting the Anzani Engine—Disassembling the Engine—Valve Grinding—Cleaning Pistons—If Anzani Engine Fails to Start—If Engine Stops—If Engine Misses—If Engine Fails to Develop Power—If Engine Overheats—Salmson Air-Cooled Engines.

The American Scorpion Engine.—The Scorpion is a four-cylinder-in-line air-cooled motor, recently announced by the Aeronautical Products Corporation of Naugatuck, Connecticut. The cylinders are 4⅝ inch bore by five inch stroke and the weight of the engine is given at 290 pounds, equipped with two magnetos and a Zenith carburetor. The engine is stated

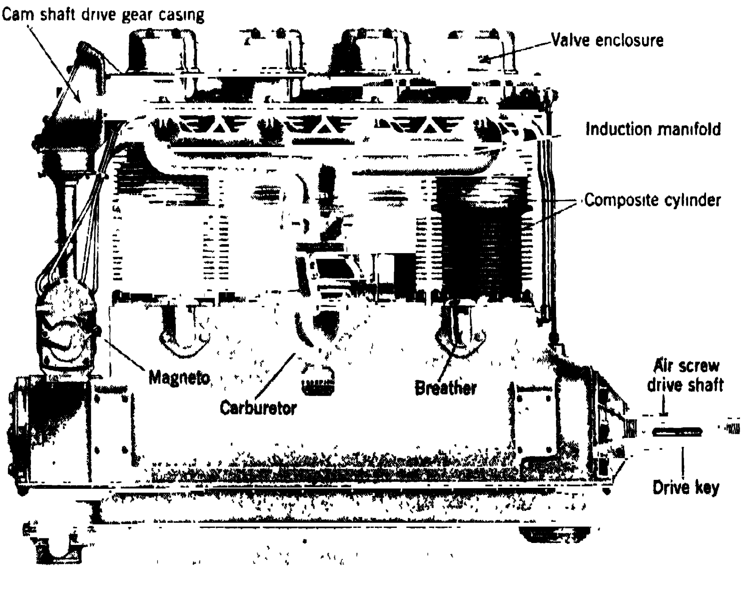


Fig. 482.—American "Scorpion" Four-in-Line Air-Cooled Engine.

to deliver 100 horsepower at 1,800 r.p.m. and as will be apparent by study of the illustration at Fig. 482, it is extremely simple in outline and rugged in construction. The distinctive feature is the overhead valve actuation for the camshaft rockers and springs on the top of the engine, completely enclosed and with oil circulation through the camshaft housing. A patented type of cantilever spring is used for the valves. The exhaust valve is salt-filled to insure adequate cooling. The cylinder construction is an alloy steel

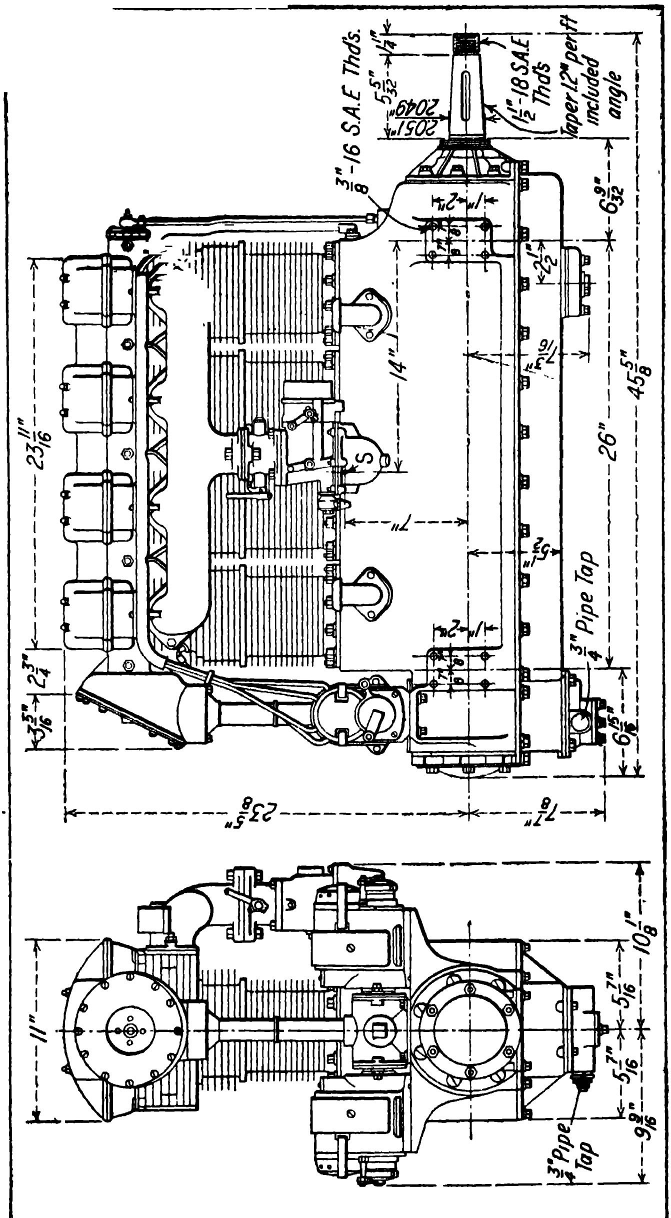


Fig. 483.—Installation Drawing Giving Principal Dimensions of American "Scorpion" Engine.

forging with the fins milled thereon, and is screwed into an aluminum alloy head which has aluminum bronze valve seats. The camshaft is driven by bevel gearing from the antipropeller end of the motor. It is stated that this motor can be mounted in the same engine bed as the Curtiss OX or Hispano-Suiza.

The installation drawing at Fig. 483 shows the main dimensions of the engine very clearly. The crankshaft is of the conventional form. The crankcase is of the barrel type of aluminum alloy, having a detachable oil pan bolted to the bottom. The design is clean cut and the engine should be remarkably easy to take care of which will make it suitable for the average flier. It has ample power to fly existing types of two- and three-place ships of moderate weight. The internal mechanism is carefully balanced so that the engine will run with minimum vibration.

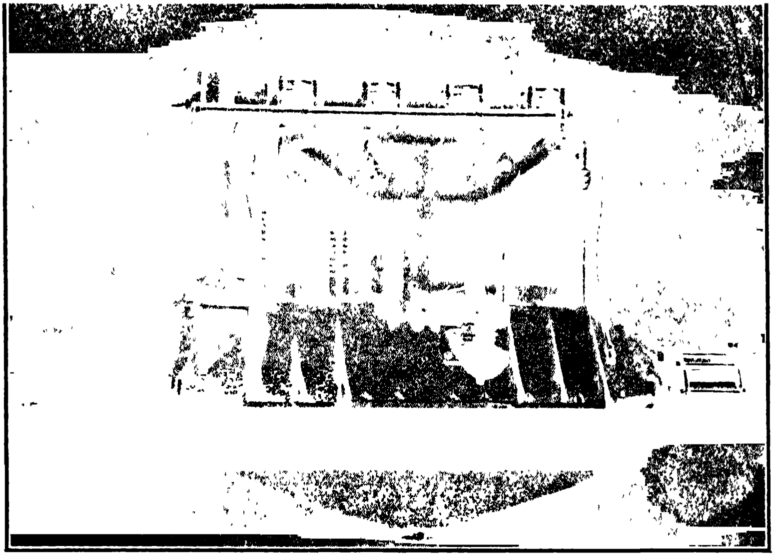


Fig. 484.—Dayton "Bear" Four-Cylinder Air-Cooled Engine.

The "Dayton Bear" Engine.—The "Dayton Bear" made by the Dayton Airplane Engine Company, of Dayton, Ohio, is a four-cylinder-in-line, air-cooled engine, built with the latest type of aluminum alloy cylinder head, on a nickel-iron, cast cylinder. The engine is not new, nor radical in any of its features, and involves no untried ideas. The "Dayton Bear" is at present rated 110 horsepower at 1,550 r.p.m., but will develop a higher horsepower at a higher r.p.m. The bore is 4.5 inches, and the stroke seven inches. The engine is shown at Fig. 484. With double magnetos and the carburetor as standard equipment, less propeller and hub, the complete engine weighs 375 pounds. Considering that this is a wet sump engine, the weight is not excessive, as the weight of an oil tank and piping should be allowed. Neither is the "Dayton Bear" of extreme lightness, as the

engine is built rugged with a view to endurance and low maintenance costs. An additional drive unit has been provided, which will drive either a C5 fuel pump, or gear oil pump, or both. This takes care of those plane builders who want a fuel pump, or a dry sump engine. In converting to a dry sump engine, it is only necessary to add the pump, and change from one to two external pipes on the crankcase. Full force feed lubrication is provided to all plain bearings in the engine, while the ball-bearings are oil sprayed.

The crankshaft is five bearing, of sturdy construction, and held in place by babbitted steel-backed main bearings, which in turn carry their load through to the cylinder head by long through-bolts, thus relieving the crankcase of all explosion strains. These through-bolts clamp the cylinder heads upon the cylinders, the seal being made by metallic gaskets. By the removal of ten nuts and two oil connections, all four heads may be removed for inspection or grinding. The cylinders also may now be lifted off individually for further inspection of pistons and rings.

The aluminum alloy heads have smoothly spherical compression-chambers, with overhead valves seated in aluminum bronze seats. Two diametrically opposed sparkplug openings are directly below the valves, and are also bronze bushed. To insure equal pressure on all cylinder heads where the through-bolts are in common, equalizers with ball seats are used. The overhead camshaft and housing, which serve to hold the cylinder heads enbloc are very similar in construction to that used in the Liberty engine. The aluminum crankcase carries all bearings mounted in the upper half, so that the lower portion or sump may be removed for inspection without disturbing the crankshaft. The oil pump is located in the sump submerged in oil. Baffle plates are inverted above the oil to prevent excessive splashing.

The cylinders are very simple, well finned barrels of nickel-iron, which are honed to a dead smooth finish. The aluminum-alloy pistons have three narrow rings near the top and are floated on the piston pin. The connecting rods are steel forgings of the eye-beam section machined all over. The engine is adaptable either as a tractor or pusher, without change, as a double ball-thrust bearing is provided at the propeller end. These qualities, combined with a comparatively low cost, should make this engine very desirable for the builder and the operator of the smaller planes of the two and three place types. It should prove very serviceable to the airplane schools, both for the student and the mechanic, as it is a type of engine familiar to nearly everyone in airplane circles.

The general specifications of the "Dayton Bear" engine are as follows:

Bore	4.5 inches
Stroke	7.0 inches
Compression ratio	5.3 to 1
Rated hp. at 1550 r.p.m.	110
Weight	375 lbs.
Height	38½ inches
Width	18½ inches
Length	47⅝ inches
Fuel Consumption	.475
Oil Consumption	.0175

LeBlond Aviation Engines.—The original development of the LeBlond Sixty design has been going on for over a period of three years, several engines having been built, thoroughly block tested, and flown in several types of airplanes in all parts of the country by a number of experienced pilots. Their reports are said to have been extremely favorable. This extended development period has allowed sufficient time to make minor improvements in the design and methods of manufacturing; in other words,

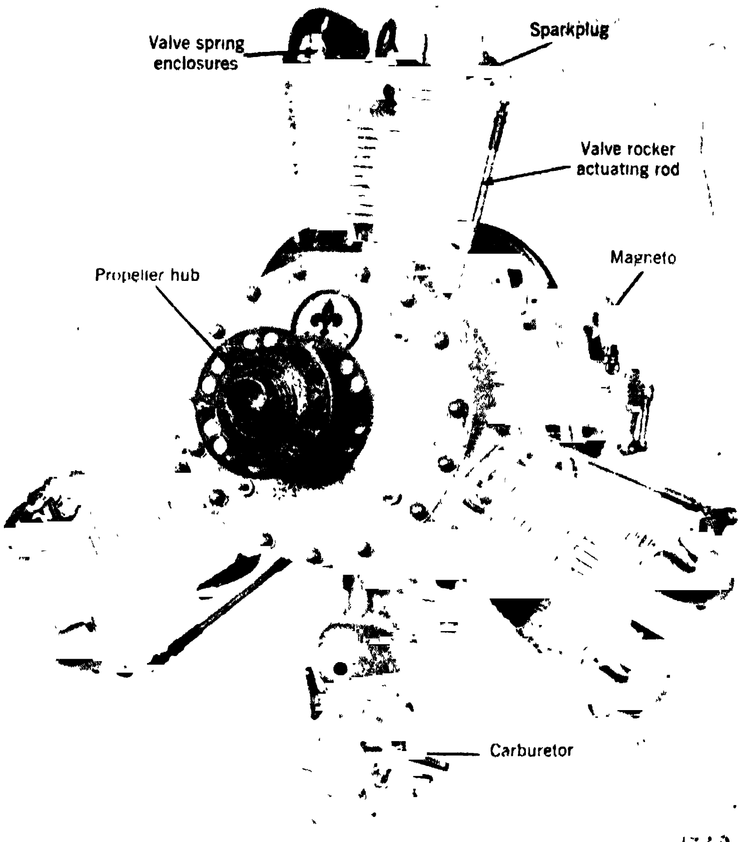


Fig. 485A.—Propeller End of LeBlond Three-Cylinder Aviation Engine.

eliminate any of the so-called "bugs" which are always present to some extent in any new engine no matter how well designed. The engineering organization responsible for this development includes men of wide experience who are well known throughout the industry. The airplane manufacturers who have decided to use or are contemplating using LeBlond engines will naturally welcome the assurance that there are sufficient resources

and manufacturing facilities behind the organization to produce a quality product in ample numbers to meet their demand. Before describing some of the more interesting features of the design, it would be well to first direct attention to the advantages in interchangeability of parts as represented in the LeBlond Forty, Sixty, and Ninety models. Fully 88 per cent of the parts used in one model can be used in either one of the others.

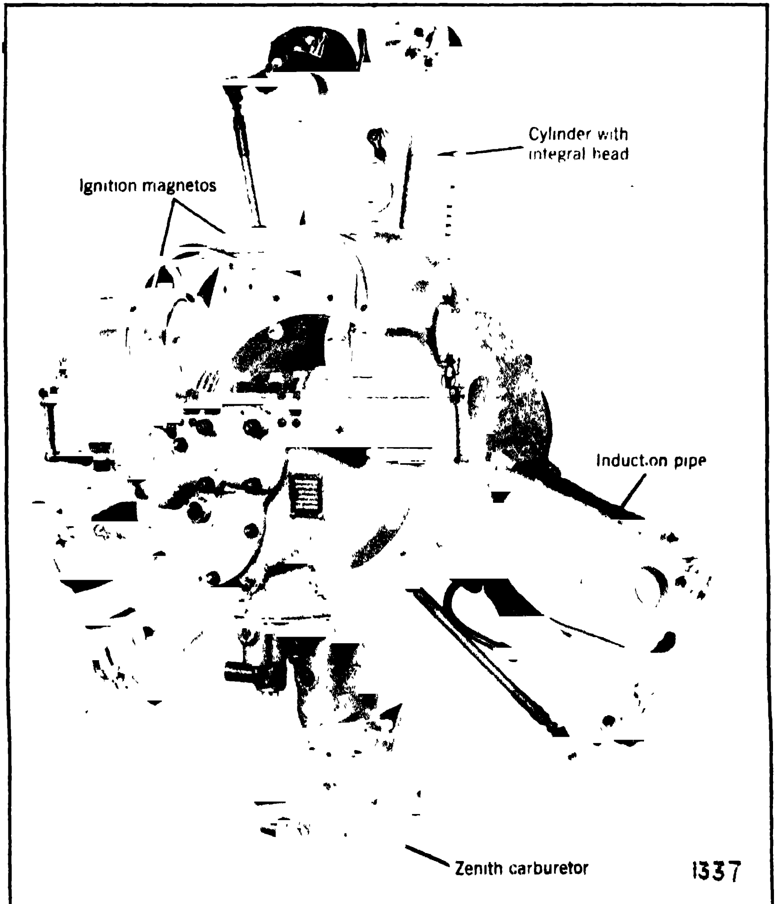


Fig. 485B.—Anti-propeller End View of LeBlond "Forty" Three Cylinder Aviation Engine.

Moreover, there is hardly an instance where the tools and fixtures, or a part of them, will not be used for producing a corresponding part, which must necessarily be somewhat different because of the number of cylinders.

LeBlond aircraft engines are said to be especially economical in the consumption of fuel and oil. This coupled with a low initial cost and slow depreciation brings air travel within the reach of most every one. The

smaller engine of the series, the three-cylinder LeBlond Forty shown at Fig. 485 is to fill the powerplant requirements of the small single-seater sport or two-seater sport and training plane. The manufacturers have attempted to make this the smoothest operating three-cylinder radial engine that has ever been built. This engine follows closely the five-cylinder design, hence the accompanying description for the most part applies. Perhaps the most interesting point of difference is the connecting rod construction, since the link rods and wristpins are identical with those used on the Sixty and Ninety models.

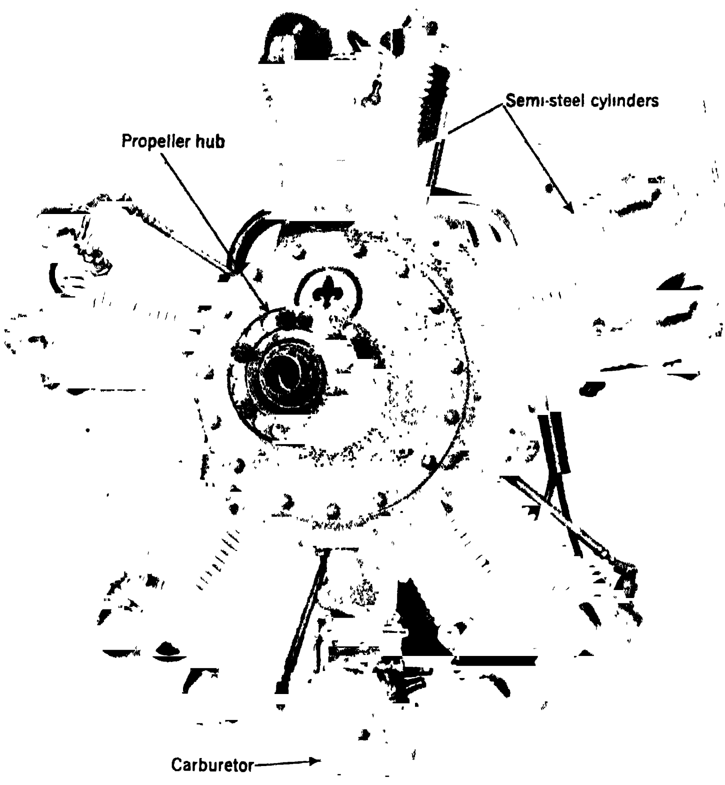


Fig. 486.—Propeller Hub End of the LeBlond Five-Cylinder, Static Radial Aviation Engine.

The five-cylinder LeBlond Sixty engine shown at Fig. 486 is particularly suited for the privately owned two-seater open or closed airplane. It can handle a light three-seater plane, but is not generally recommended as the makers believe in plenty of reserve power as a matter of safety. The illustration at Fig. 487 A shows the connecting rod construction used in the LeBlond Sixty. The rods are completely assembled on the crankshaft and

the whole assembly is inserted into the crankcase through the large opening at the front. The connecting rods are heat treated drop forgings of nickel steel. The babbitt in the master rod is applied directly to the steel, thus eliminating the troubles encountered with a separately fitted bronze backed bearing. Although the rods are fairly light, the construction is extremely rigid and perhaps as simple as an articulated rod arrangement could be made.

The crankshaft illustrated at Fig. 487 B is shown as an assembly before the connecting rods are attached. This piece is a heat-treated drop-forging of nickel-chromium steel and it is finished all over. The counterweights are made from a tough grade of bronze, being supported against lugs on

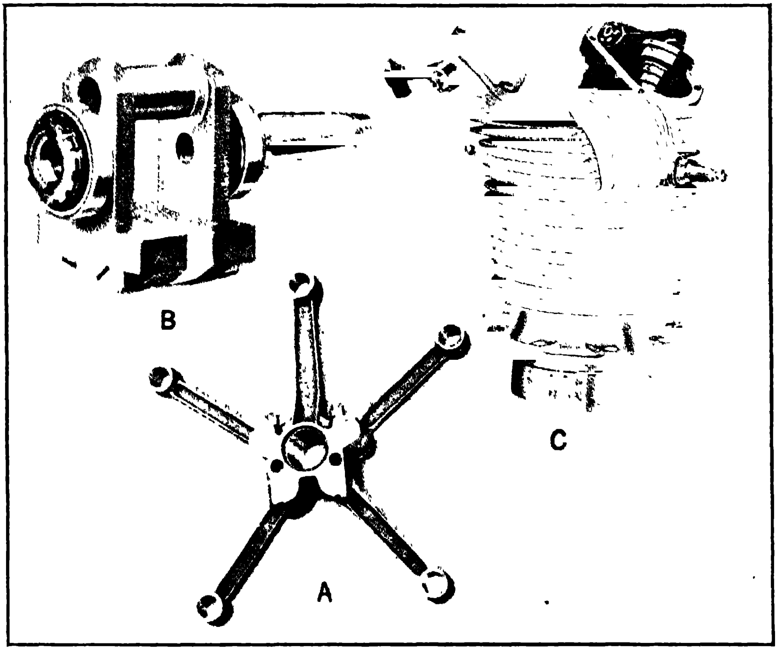


Fig. 487.—Parts of LeBlond Five-Cylinder Radial Engine. A—Master Connecting Rod Assembly. B—Crankshaft and Ball Bearing Assembly. C—LeBlond Cylinder.

the crankshaft and each held in place by two screws. The rear ball-bearing is finally supported in a steel sleeve held in the central wall of the crankcase, while the front ball-bearing which also carries the propeller thrust loads, is supported in the crankcase cover that closes this large opening at the front of the crankcase.

The crankcase shown at Fig. 488 A is of cast aluminum alloy, heat-treated to give high tensile strength. The inlet passage is cored in this casting, thus effecting a small number of manifold joints as well as providing other important advantages. The cam follower bushings, which are pressed in place, are cast from a fine grade of hard iron and the holes

are ground to close limits. The cam followers and rollers are assembled into the crankcase before the gearcase assembly is attached to the flange at the rear as shown at Fig. 488 B.

It may be observed from the illustration of the gearcase assembly at Fig. 488 C that the cam drive shaft pilots into the end of the crankshaft and is driven by offset lugs which will not permit of incorrect assembly. In other words, the cam and magneto timing doesn't need to be reset each time the gearcase assembly is removed. The cam floats on the cam drive shaft and lines up with the

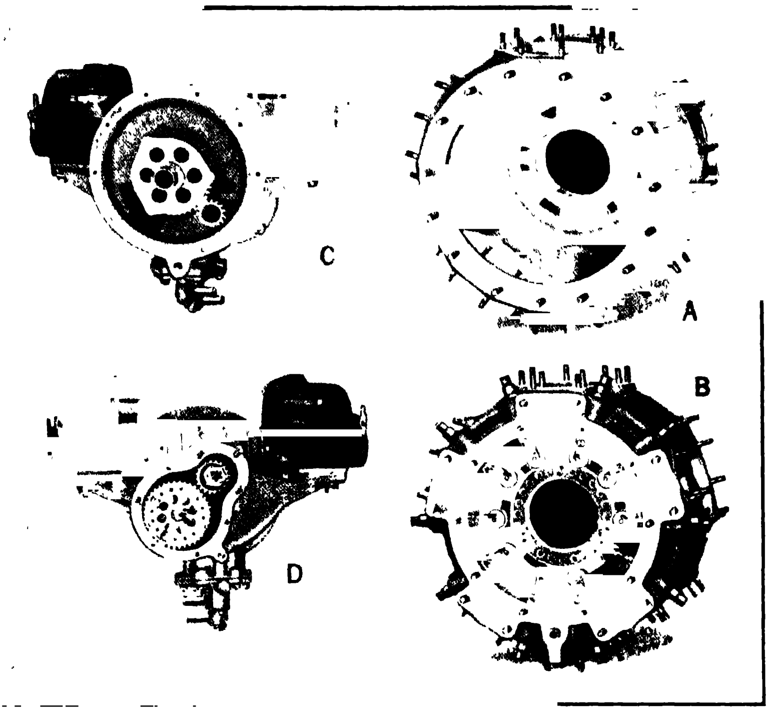


Fig. 488.—Views Showing LeBlond Crankcase Construction. A—Crankcase with Cylinders Removed. B—View of Crankcase with Cam Follower Rolls and Plunger in Place. C—View of Accessory Case Showing Three Lobed Cam and Magnetos. D—Rear View of Crankcase.

cam follower rollers when the gearcase assembly is in place. A single ring cam as shown is used to operate all valves. In the three-cylinder engine a two lobe cam turns one-fourth crankshaft speed; in the five-cylinder engine a three lobe cam turns at one-sixth crankshaft speed; while in the seven-cylinder engine a four lobe cam turns at one-eighth crankshaft speed. The cam has a bronze bushing, and the cam drive shaft, idler shaft, and magneto drive shaft are also carried in bronze bushings and all are fed oil directly under pressure from the pump. The timing of the valves is effected through the adjustment provided in the gear and timing flange by the series of holes and the four screws.

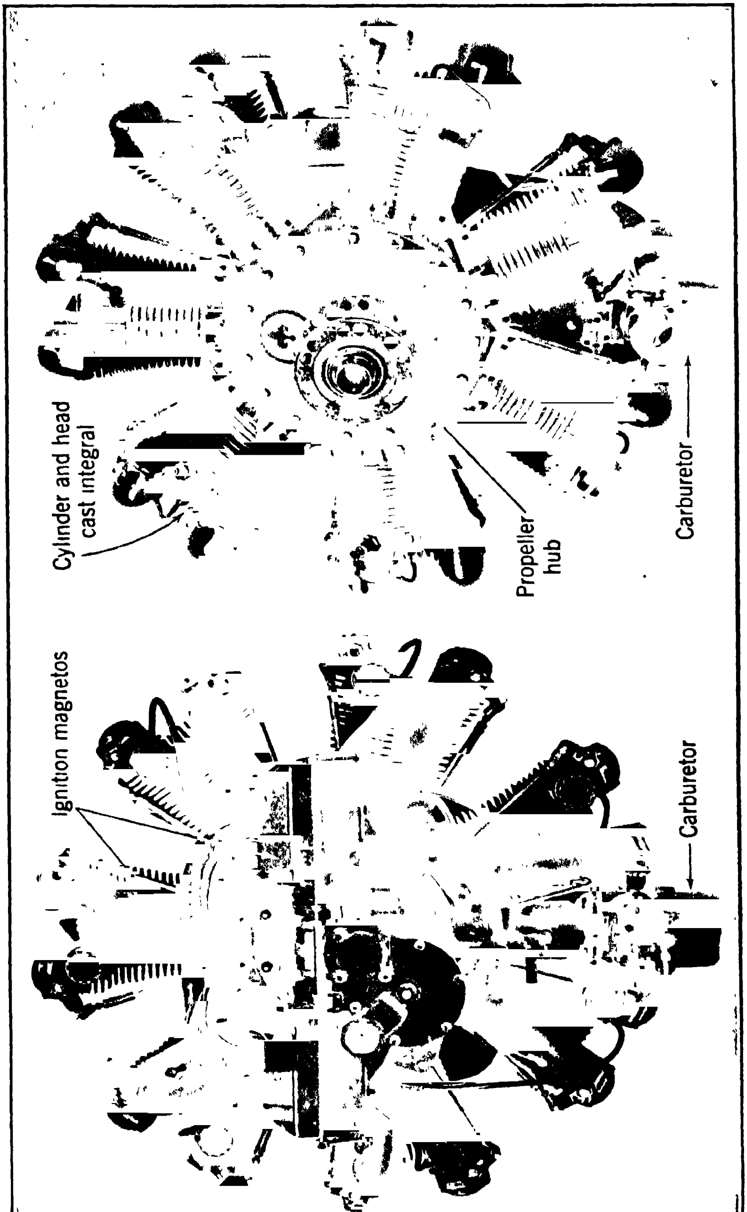


Fig. 489.—Views Showing LeBlond 90 Nine-Cylinder Radial Air-Cooled Engine. At Right—Propeller End. At Left—Anti-Propeller End Showing Carburetor and Magneto Installation.

The oil pump is removable as an assembly. It contains two compartments, one for the pressure and the other for the scavenging gears, each with screens for trapping foreign particles in the oil. The driving gears are of steel and the driven gears of bronze. An oil pressure relief valve for controlling the oil pressure is also located conveniently in the pump body. The connections for oil lines to and from the tank can be adjusted to any desirable position.

The cylinder which is shown at Fig. 487 C is a one piece casting of the finest grade of nickel iron with integral cooling fins of ample surface. The valves seat directly in the cylinder head and the external portions of the valve gear is enclosed. All valve gear parts are interchangeable. The outside of the cylinder is finished with a fine grade of black stove enamel which adds greatly to the appearance, and to the heat dissipating qualities of the cylinder as well. The cylinder bores are honed, giving the finest surface obtainable. The cast-iron cylinder has many advantages when used on an engine for commercial purposes. First of all, there is little danger of cylinder failure nor an appreciable loss in power when conditions are such as to cause cylinder temperatures above normal. It has also been found that excellent fuel economy is obtained, and that no harm will result from sudden changes in temperature as is sometimes the case with other materials and composite construction. It is impossible to produce a different type of construction of equal output and durability commercially with anywhere near the low cost, ease and certainty of production that results from the use of a single piece cast-iron cylinder.

The pistons are made from a cast aluminum alloy. There are two compression and one oil scraper ring located above the piston pin on each one. The piston pin is hardened and lapped and it floats in the rod and piston, there being duralumin plugs in each end to prevent scoring the walls of the cylinder.

Zenith carburetors of the concentric float type and provided with altitude mixture control are standard equipment on all models. The carburetor is attached to the lower side of the oil sump, the mixture passing through an opening in the sump where the heat from the oil surrounding the walls helps to vaporize any heavy ends of the fuel. Air heaters will be available as extra equipment for customers who prefer them. Two Scintilla magnetos for dual ignition are standard equipment on each model. Booster type units can be furnished at slight additional expense.

The seven-cylinder LeBlond Ninety engine shown at Fig. 489 is an ideal powerplant for any of the three-place commercial ships that have been using a 90 horsepower engine. The makers firmly believe that it occupies less space and represents less head resistance than any engine of approximately its horsepower so far introduced. The most interesting detail which is different from the two smaller models is the connecting rod construction. The specifications of the various engines follow:

SPECIFICATIONS OF LE BLOND FORTY

Type	Air-cooled Radial
No. of Cylinders	3
Bore	4.125 in.

Stroke	3.750 in.
Displacement	150 cu. in.
Rated Horsepower	40 at 1900 R P.M.
Weight, complete	168 lbs.
Diameter overall	32.75 in.
Length overall	21.94 in.
Fuel Consumption (lb. per hp. hr.)	Max. .55 at rated power
Oil Consumption (lb. per hp. hr)	Max. .03 at rated power

SPECIFICATIONS OF LE BLOND SIXTY

Type	Air-cooled Radial
No. of Cylinders	5
Bore	4.125 in.
Stroke	3 750 in.
Displacement	250 cu. in.
Rated Horsepower	60 at 1800 R. P. M.
Weight, complete	210 lbs.
Diameter overall	32.75 in.
Length overall	21.56 in.
Fuel Consumption (lb. per hp. hr.)	Max. .55 at rated power
Oil Consumption (lb per hp. hr.)	Max. .03 at rated power

SPECIFICATIONS OF LE BLOND NINETY

Type	Air-cooled Radial
No. of Cylinders	7
Bore	4.125 in.
Stroke	3 750 in.
Displacement	350 cu in.
Rated Horsepower	90 at 1850 R. P. M.
Weight, complete	250 lbs.
Diameter overall	32.75 in.
Length overall	22.25 in.
Fuel Consumption (lb. per hp. hr.)	Max. .55 at rated power
Oil Consumption (lb. per hp hr.)	Max. .03 at rated power

The Warner "Scarab".—The engine is a seven-cylinder, static, air-cooled, radial of conventional design rated 110 horsepower at 1,850 r.p.m., though it has developed 122 horsepower at 1,950 r.p.m. which has made an excellent record since its introduction. Dry, without starter or hub, it weighs 270 pounds or 2.45 pounds per rated horsepower. The compression ratio is 5.2 and it operates at a mean effective pressure of 112. The displacement is 422 cubic inches and the bore and stroke 4.25 inches by 4.25 inches. It is stated that specific fuel consumption at full throttle is .487 pounds per horsepower hour or 9.3 gallons per hour and that oil consumption is .008 pounds per horsepower hour. The engine is quite small and presents a very clean appearance. The overall diameter is 35½ inches while the overall length is 27½ inches. All accessories are placed in the rear and, according to Warner, designed with a view to minimizing the amount of time required for installation and to make it comparatively easy to streamline the cowling. The engine is shown at Fig. 490.

Cylinder barrels are chrome molybdenum forgings, while the heads are of Bohn aluminum alloy. Adequate cooling fins are provided; they extend over the head and around the valves. The combustion-chamber is hemispherical with two valves, one intake, and one exhaust at the sides, and

with two AC sparkplugs, one in front and one in back, diametrically opposite. Aluminum bronze valve seats are shrunk into the head; the two valves are of the tulip type set 45 degrees apart. They are $1\frac{1}{2}$ inches in diameter and have a lift of .406 inch. The intake valve is of tungsten steel while the exhaust valve is a cobalt alloy. The double valve springs are exposed, as are the rocker arms, as far back as the fulcrum point. Behind

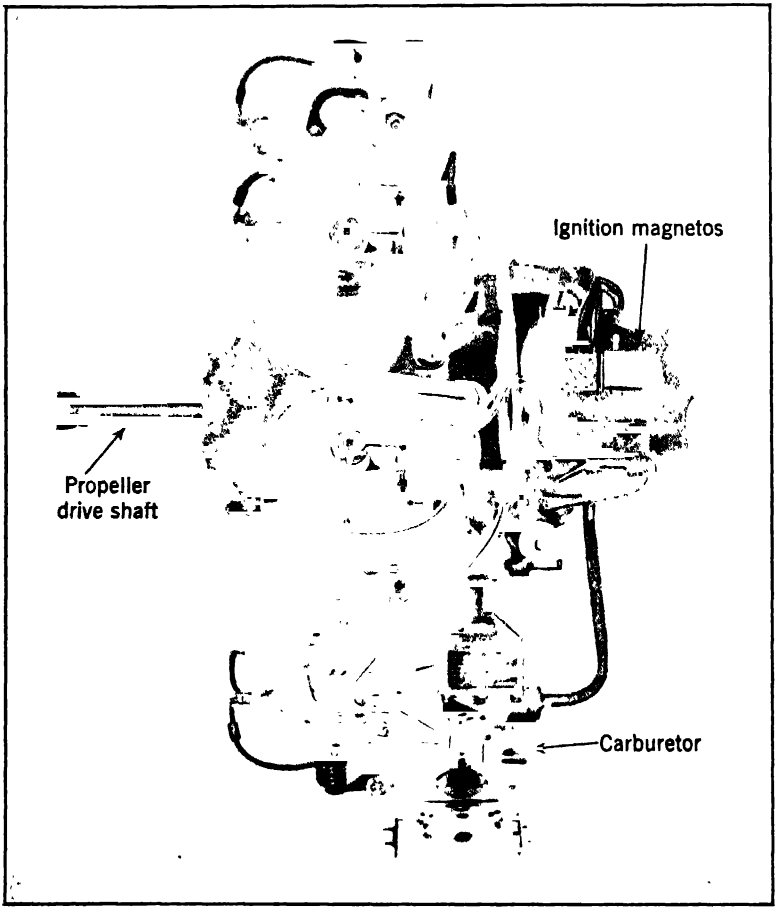


Fig. 490A.—Side View of Warner "Scarab" Engine.

this, the valve mechanism is housed in an aluminum alloy box, the aluminum cover of which may be easily removed to make tappet adjustments. The valve gear mechanism is thus protected from dirt, while the springs are exposed for cooling purposes. The sides of the box also act as supports for the rocker arms and are bolted to the cylinder head with two $\frac{5}{16}$ inch bolts. The rocker arm operates on a bronze bearing lubricated by a Zerk

Alemite fitting. The cylinder head is shrunk and bolted to the barrel. Eight bolts are used to attach the head to the barrel and eight bolts are used to hold the cylinders to the crankcase. The skirt of the cylinder barrel projects about 1½ inches into the crankcase to prevent surplus oil from running into the cylinders.

Permanent mould pistons of Bohnalite are used. They are of flat head design with two American hammered compression rings and one Perfect Circle oil scraper ring. They weigh only one pound five ounces each. The

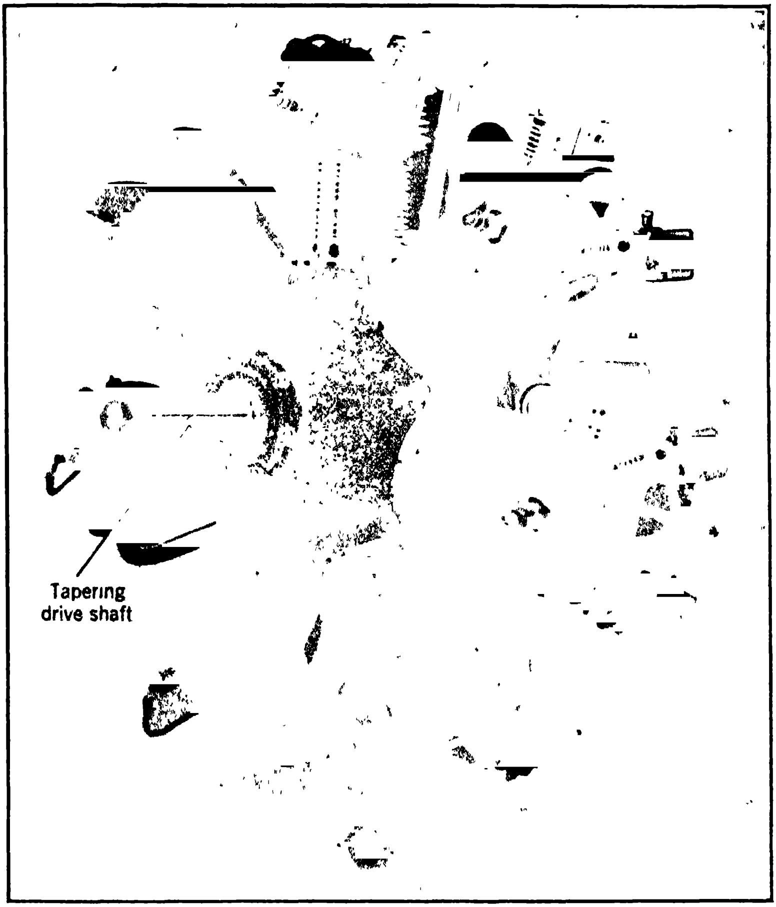


Fig. 490B.—Three Quarter Front View of Warner "Scarab" Engine.

piston pin is full floating and bears directly on the piston with bronze bearings in connecting rods. Both master rod and link rods are of one section. The master rod is of two piece design with a babbitted bearing for the crank pin. Through bolts locate the wristpins which take their bearings directly in the master rod big end. This construction is said to eliminate

plugging the pin. There are separate oil leads from the crankpin to each link rod bearing. The crankshaft is a single piece machined on all surfaces. It is very short, making for greater stiffness. There are two main bearings and one thrust bearing. The propeller hub flange is spliced on to the crankshaft and is part of the engine. The accessory drive, connected to the crankshaft by an Oldham coupling is in the rear.

The two cam rings in the rear are each one piece forgings, with the gear on the inside, an integral part. The cam rings each run at 1/8 engine speed and each has four lobes. In contact with the rings are the roller followers working in permanent mould aluminum valve guides and operating duralumin push rods with pressed ball ends. The push rods are enclosed in aluminum tubes and are fitted with a roller tappet at the upper end.

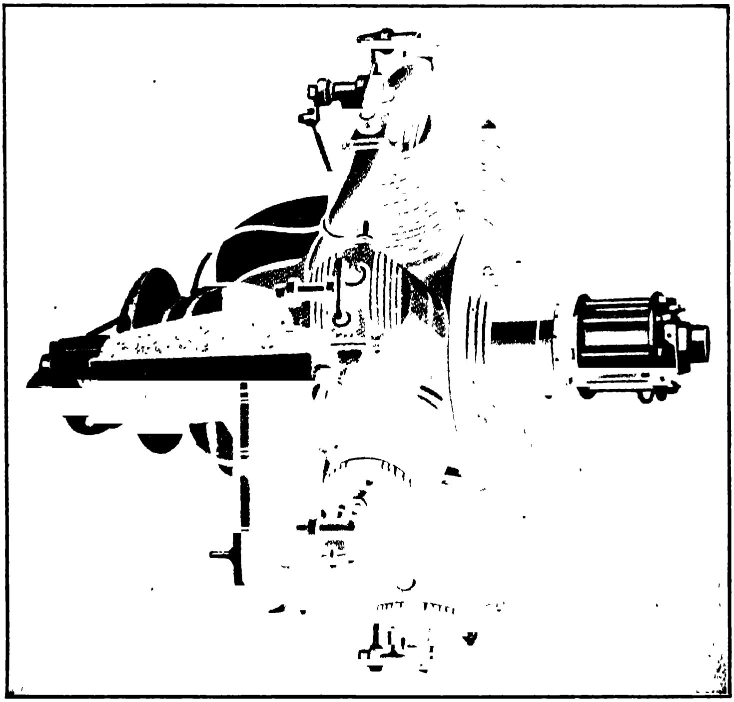


Fig. 491.—Super Rhone Radial Air-Cooled Engine.

The crankcase is made up of two heavily ribbed halves joined on the center line of the cylinders. This construction is said to facilitate the assembling of the connecting rod and crankshaft as a unit, reducing production costs. In addition, it assures more uniform and sound castings and eliminates a number of foundry problems. It is made of aluminum alloy. The intake manifold induction system is carried in a separate casting bolted to the rear of the crankcase. It consists of annular induction ring with manifold pipes connected to it and bolted to the sides of the cylinders. It is circular with a diameter of seventeen inches having eight mounting studs.

Mounted below and to the rear of the cylinders is the Stromberg NAS5A carburetor with the intake heated by the exhaust gases of the two lower cylinders. Between the carburetor and the annular induction ring is the oil sump, connected to the scavenger oil pump which feeds to the oil tank, from where the oil is forced by the pressure pump to all of the plain bearings and by splash to the cylinders. The engine is equipped with two Scintilla magnetos, each mounted at 33 degrees from the center line so as to make them more accessible and to allow for the mounting of a starter between them. The magnetos are driven through bevel gears, on SRB ball-bearings, from the counter shaft coupled to the crankshaft.

The general specifications on the Warner "Scarab" engine are as follows:

Type	Static radial, air cooled
Number of Cylinders	7
Number of Cycles	4
Propeller Drive	direct
Rated power	110 hp.
Rated speed	1850 r. p. m.
Maximum power	122 hp.
Maximum speed	1950 r. p. m.
Weight dry, without hub or starter	270 lb.
Specific Weight	2.45 lb. per hp.
Guaranteed fuel consumption at rated power	50 lb./hp./hr.
Guaranteed oil consumption at rated power	01 lb /hp./hr.
Compression ratio	5.2
Mean effective pressure	112
Bore	4½ in.
Stroke	4½ in.
Displacement	422 cu. in.
Overall diameter	35½ in.
Overall length, without starter	27½ in.
Diameter of mounting ring	17 in.
Ignition	dual Scintilla
Carburetion	Stromberg NAS5A

The Super Rhone Engine.—This is a modification of a very popular wartime engine that was built originally to be a revolving cylinder fixed crank type. A special conversion has been designed and patents applied for by Charles E. Quick and the modified engine is produced by a firm who purchased the wartime surplus from the Government. The LeRhone rotary engine, which forms the basis of this engine, was used by France and England in very large quantities and with excellent results. Converting the engine to a fixed radial type has resulted in a marked decrease in fuel and oil consumption with a resulting increase in power output because the engine can be run faster with fixed cylinders and the horsepower formerly used in turning the cylinders through the air is now delivered to the crankshaft. Most of the American pursuit pilots who were instructed at the Third Aviation Instruction Center of the A. E. F. at Issoudon, Indre, France, received their preliminary training on airplanes equipped with the Le Rhone engine. The cylinders are of steel with circumferential flanges turned on the barrel and longitudinal flanges milled in the heads. In the rotary form, the gasoline was admitted through a hollow crankshaft, and

castor oil was necessary for engine lubrication, and large quantities of oil were thrown out of the exhaust ports as the cylinder assembly revolved. This made this form of engine an exceptionally dirty form to ride behind, which of course, was true of other rotary types such as the Gnome and Clerget. Complete cowling interfered with the cooling and was not used so pilots trained with the rotary engines know the taste and smell of partially burned castor oil very well. None of these faults are found in the Super Rhone.

From the nature of its construction, with its taper jointed counterbalanced crankshaft of single throw, complete disassembly can be accomplished by a mechanic of ordinary ability in thirty minutes time, thereby reducing lost flying time in schedule service to a minimum. The saving in weight through the elimination of the radiator and the water piping and connections, as well as the water itself, permits greater pay-load than with the water-cooled engine, and, at the same time, it removes a cause of frequent trouble with consequent forced landings. The absence of the radiator reduces head resistance, giving greater speed and maneuverability, and again reduces cost. The internal construction of parts is practically the same as the LeRhone engine described at some length in a preceding chapter.

In the Super Rhone engine shown at Fig. 491 any complications in effective air-cooling have been entirely overcome by a simple process which admits fresh air, under atmospheric pressure, to the crankcase, and which forces a complete change of air within the crankcase with each revolution. Thus, excessive accumulation of heat at the center is eliminated by the free passage of fresh cool air, this tending also, by regulation of temperature and pressure, to reduce oil consumption to a minimum.

The engine mounting which forms the basis of the conversion also serves as an intake manifold, is a strong, clean aluminum casting of tested strength. It carries, on its rear and lower side, a flanged face opening to which the carburetor is attached and from which opening the explosive gases are carried to a central chamber from which they are conducted by individual ducts to apertures in the periphery of the casting where the intake pipes that lead to each cylinder are fastened. Thus each cylinder draws its gases as needed from this central chamber, eliminating thereby the excessive amount of gas in any one cylinder which is the most frequent cause of fouling in air-cooled engines and often attributed to lubrication faults. This engine mounting has two properly surfaced flanged extensions toward the rear, two inches wide and thirteen inches long, which form the means of fastening the engine to two engine beds as is the practice in water-cooled types. This cheapens installation costs by the elimination of expensive circular mounting brackets, and readily adapts the engine to installation in the usual manner. The engine mounting, also, carries the magneto and oil pump, and the scavenger pump, and it is to be noted that the engine proper may be withdrawn from this mounting without disturbing fuel, oil or electrical connections and controls.

The crankshaft of the Super Rhone has been carefully and efficiently counterbalanced, and vibration is reduced to a minimum. The rear end of the shaft extends backward about sixteen inches, and from it are driven

the magneto, oil pumps and distributor. The lubrication of the Super Rhone is effected with ordinary mineral oil of high viscosity, easily obtainable in any locality. Castor oil is not needed. Oil is supplied to the pump from which it is forced through a duct drilled through the length of the crankshaft to the working parts.

SPECIFICATIONS

The general specifications of the Super Rhone engine are as follows:

Type	Air-cooled fixed radial
Number of cylinders	Nine
Bore	105 mm. or 4.13 in.
Stroke	140 mm. or 5.51 in.
Piston displacement	667 cu. in.
Compression ratio	5.2 : 1
Direction of rotation	Counter-clockwise
Fuel consumption	9½ to 10½ gal per hr.
Oil consumption	¾ to 1 gal. per hr.
Rated power	120 hp.
Normal speed	1400 r.p m.
Weight	340 lb.

The installation dimensions of the engine are:

Length, overall	36 in.
Diameter, overall	36 in.
Engine bed flanges, inside clearance	11 9/16 in.
Engine bed bolts, center to center	13 9/16 in.
Distance, bottom of carburetor to engine bed	13 in.
Distance, hub line to carburetor	19 in.

Velie Aircraft Engine.—Velie Motors Corp., Moline, Ill., was one of the latest automobile manufacturing concerns to enter the aircraft field. This company is now in production on a five-cylinder, four-cycle, air-cooled radial aircraft engine, developing 70 horsepower at 1,800 r.p.m., and 80 horsepower at the maximum of 2,000 r.p.m. The engine is being used in the "Monocoupe" airplane of Mono-Aircraft, Inc., also of Moline. The engine, dry, without hub or starter, weighs only 210 pounds, giving a weight of 2.63 pounds per rated horsepower. Installed in the two-passenger Monocoupe, tests have shown that it will take off in three to five seconds, cruise at 85 m.p.h., with a top speed of 100 m.p.h., land at 30 to 35 m.p.h., and operate with a gasoline consumption of approximately 20 miles to the gallon.

Special features of the engine, shown at Fig. 492, are its solid master connecting rod and two-piece crankshaft, simple valve mechanism and absolutely clean lines in front, making for minimum head resistance. The main crankcase is one piece with the mounting ring cast integrally. Bore and stroke are 4⅛ inches by 3¾ inches and piston displacement is 250.6 cubic inches. The engine has a compression ratio of 5.2. Diameter of the mounting ring is 12¾ inches; height, or overall diameter, is 32 inches and the length without starter is 27 inches. The guaranteed fuel consumption at the rated

horsepower is .55 pound per horsepower-hour. Oil consumption is .025 pound per horsepower-hour.

The gear case cover carries the magneto, oil pump and tachometer drive. Three ball-bearings support the single-throw, two-piece crankshaft, the bearings being placed one on each side of the crankpin and the third just behind the propeller hub. The last-named bearing takes the propeller thrust as well as the radial load.

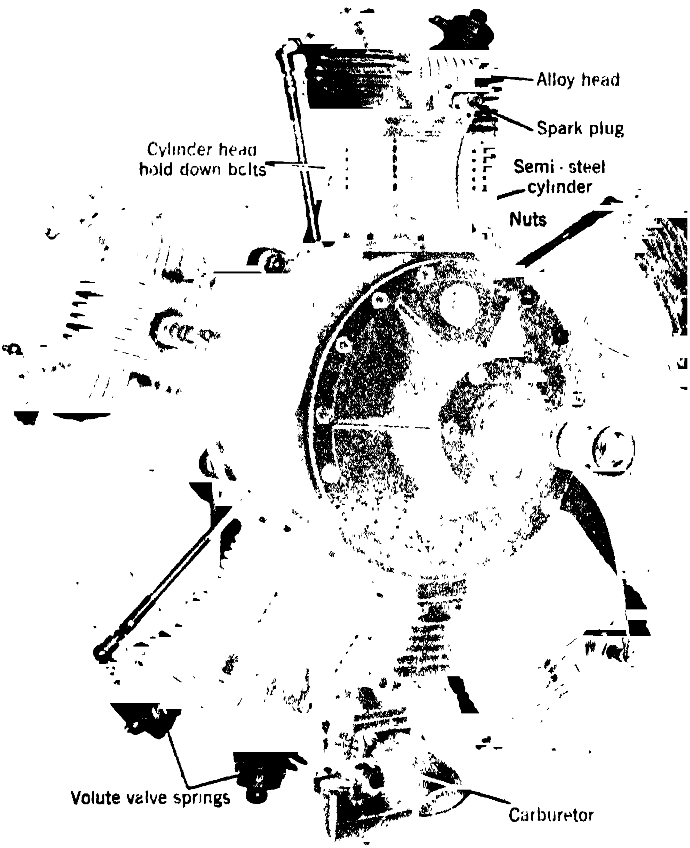


Fig. 492.—Velie Five-Cylinder Static Radial Aircraft Engine.

To assemble the single-piece master rod the shaft is divided into front and rear sections, the crankpin being integral with the forward section which transmits the power to the propeller hub carried by it. The crankpin telescopes into the rear section and is carried completely through it. A bolt passes through the hollow crankpin and crankcheeks to assemble the crankshaft halves while the two telescoping crankpin parts are located by means of a key.

Use of the split type crankshaft has become more popular recently in this country, since it eliminated the assembly bolts in the split master rod necessary with the solid shaft. These bolts, especially in a radial engine, are subject to considerable shearing strain, while any inaccuracy of fit or wear of the bolts permits relative motion of the rod halves. The babbitt bushing, spun in the rod, bears directly on the crankpin itself, and four connecting link rods are attached to the master rod by means of wristpins. The link rods are bronze-bushed for the piston end wristpins and all bearings are oiled under pressure.

Cylinders are of nickel steel with integral fins. Heads are cast of aluminum alloy. Each cylinder has one inlet and one exhaust valve, seating in the head on aluminum bronze. Valve lifters are of the roller type and both intake and exhaust valves operate from the same cam. Silchrome steel is used for the valves and both intake and exhaust have a diameter of 1 $^{11}/_{16}$ inches with $^{1}/_{32}$ inch stems.

The large cylinder fins, the head construction and the valve proportions are given major credit for the very low temperature claimed to be shown by the new engine in block and flying tests.

Two gear pumps comprise the oil assembly. One supplies oil under pressure to the engine bearings and the other is used for scavenging. Oil is taken from the tank by the pressure pump and is delivered to the oil collector ring, where it is forced through the center of the crankshaft to crank and wristpin bearings. The discharged oil is returned to the tank by the scavenger pump. There are only two oil lines in the entire assembly, the one for the inlet, or suction impulse, and the other for the outlet, or scavenging action. The skirt of the cylinders extends into the crankcase, acting as an oil shield, thus preventing excess oil from entering the cylinders while also keeping down the overall diameter.

Ignition is furnished by two Scintilla magnetos located at the rear of the engine, which fire two sparkplugs in each of the five cylinders. The engine is equipped to take the standard mounting of Eclipse electric starter, which, complete with battery, weighs only 40 pounds and is optional equipment. The engine is completely equipped, ready to operate, with Zenith carburetor, carburetor heater, two magnetos, propeller hub, mounting ring, exhaust ring, complete set of tools and instruction book.

Features of the ASSO 80T Engine.—The crankcase is in two parts. The upper, together with the cylinders, is one block election casting. The cylinder sleeves are pressed into the cylinders. The lower part completely encloses and protects the moving parts and contains the oil-pump. Separate cylinder-heads are used for each cylinder, cast in electron, in one block with the intake-manifold and exhaust-port. Pistons are made of aluminum alloy and are hollow-shell castings with three compression rings at the upper end, and oil-scraper ring at lower end. Connecting rods are of special heat-treated steel, double T section. Seven crankshaft-bearings of the plain journal type are used and in the front, between first bearing and propeller-hub a ball thrust bearing is interposed to take propeller thrust. The propeller-hub is of the Rudge-Whitworth type. Two camshafts one on each side of the engine operate the intake and exhaust valves. The right hand camshaft actuates the gasoline pumps, the left one the oil-pump. Ignition is by double ignition, two Bosch magnetos

being placed transversely at the anti-propeller end of the crankcase. Lubrication is by pressure feed. The oil-pump is vertical and dips into the lower part of the crankcase sump. It is a double action pump; pumps oil from sump and sends it to tank or oil-cooling apparatus and pumps oil under pressure to various cams and bearings. The construction of this engine is clearly shown at Fig. 492 A. Two carburetors are used, one at each end of the engine, each one supplying three cylinders. The carburetor air intakes take warm air from the cylinders.

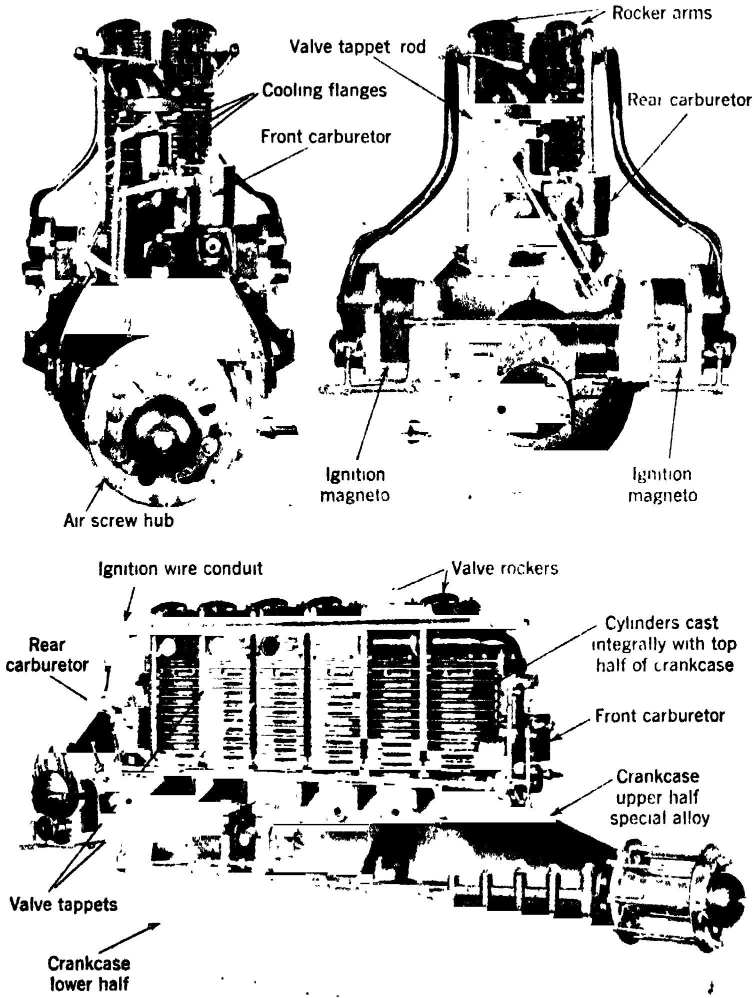


Fig. 492A.—Views of the Isotta Fraschini ASSO 80T Air-Cooled Engine Which Has Six Cylinders Cast Integrally with Top Half of Crankcase, Which is a Special Magnesium Alloy Known as Electron. Steel Liners Are Used in the Cylinders.

SPECIFICATIONS

Isotta-Fraschini Aviation Motor	Type "ASSO 80T"
Cooling system	Air
Bore	3 15/16 in.
Stroke	3½ in.
Cylinders	6 in line
Total cubic capacity	402.75 cu. in.
Hp. 80	1400 r.p.m.
Hp. 100	1550 r.p.m.
Compression ratio	1 :5.5
Gas consumption per Hp /hour	0 507 lbs.
Oil consumption per Hp /hour	0.043 lbs.
Weight of motor with hub	242 lbs.

Anzani Aviation Motors.—Leaping into fame through the crossing of the channel between England and France in July, 1909, Anzani Radial Air-cooled Motors have retained their place as the most widely distributed aviation motors in the world. M. Anzani has always envisaged the sport airplane, a machine so simple in its powerplant that it could be cared for by the average owner and that repairs would be even more simple than for the average motor-car engine. Following this idea, Anzani engines have always been simple and strong. This year certain changes have made the engine even more simple and even more reliable than ever before and these same changes have resulted in a tremendous saving in lubricating oil consumption.

All Anzani engines are built to conform to the severe standards imposed by the French Government for aircraft engines, which standards are far more severe than those of the United States Department of Commerce. The revolutions have been kept low to insure long life, the normal speed being from 400 to 1,800 r.p.m. The fuel consumption for Anzani engines, according to the 50-hour tests run by the French Government at the Chalais Meudon Laboratory, shows an average specific fuel consumption during the 50-hour runs of 260 grams per horsepower-hour. With the new oiling system, a specific oil consumption of ten-twelve grams per horsepower-hour can be counted upon.

Cylinders and Crankcase.—The cylinders (A) are of an iron-nickel-steel mixture, cast at the Anzani foundry. This alloy is extremely hard and gives wonderful service. The cooling fins are deep and thin, giving ample radiation. The valve guides, sparkplug bosses, etc., are cast integral. The lower end of the cylinders form a long sleeve extending into the crankcase, at the same time acting as an oil shield. The cylinders are held down by two long studs each, which extend to the heads and which are so pinned at the crankcase end that they are carried on the crankcase through bolts (AF) which pass through them. Thus, the force from the explosion pressure is carried directly from the cylinder head through these alloy steel studs to the crankcase through bolts (AF), which also serve to hold the engine on the mounting plate. Simply removing the two nuts from the exhaust manifolds and the two cylinder hold down nuts permits the cylinder to be withdrawn without disturbing any cowling, etc. The inlet header pipes (Q) are a sliding fit into the inlet manifold (AN), which is cored in the crank-

case, so that the header comes right off with the cylinders and no joints are broken. Carrying the cylinders on the studs and the crankcase assembly on the same studs allows us to carry nearly all of the major stresses directly on alloy steel members, permitting the use of simple light castings, which reduce weight and increase reliability. In fact, the crankcase simply acts as a spacer and oil container and the ends as plates to carry the main bearing forces to the through bolts. The crankcase itself is a two-piece aluminum casting (AR), split vertically and fitting together with a dovetail joint. The front portion is hemispherical on the nose, so as to keep down

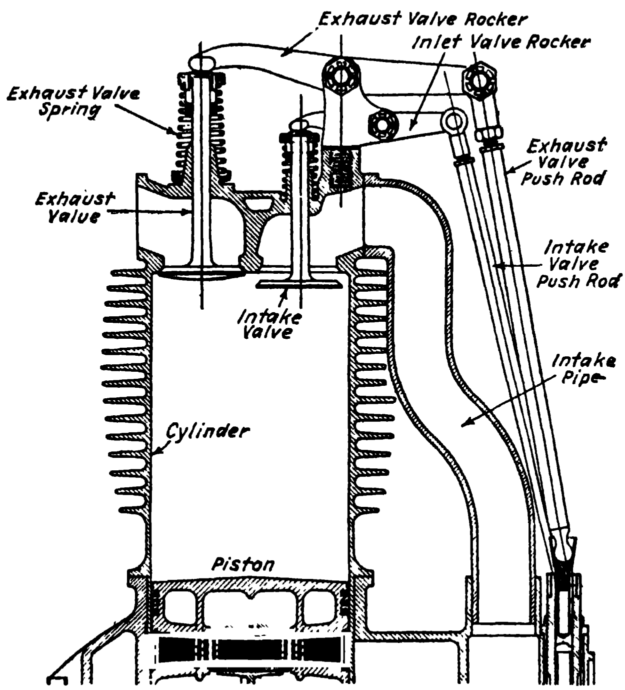


Fig. 493.—Sectional View of Cylinder Showing Valves and Actuating Rocker Arms of Anzani Engine.

head resistance. It carries the front main (AM) and thrust bearings (AL, AP). The rear half carries the rear main bearing (AQ), the camhousing, tappet guides (R), inlet manifold (AN) and mount ring, while the magnetos (AB) mount on the camhousing cover, which bolts to the rear half. The sectional view of the cylinder at Fig. 493 shows the construction very clearly. The lettering on Fig. 495 is intended to accompany the descriptive matter and instructions which follow.

Pistons.—The pistons (B) are of aluminum alloy, having a convex head which thickens towards the skirt so as to better conduct the heat. The

pistons are fitted with three rings and the skirt is relieved annularly the width of the piston ring, so as to feed oil into this member and to prevent rubbing on the cylinder wall due to uneven expansion. The piston pin bosses are supported by a heavy rib cylindrical in form and concentric with the piston wall. This patented feature gives a very stiff support to the piston pin in all directions and any expansion is concentric with the piston

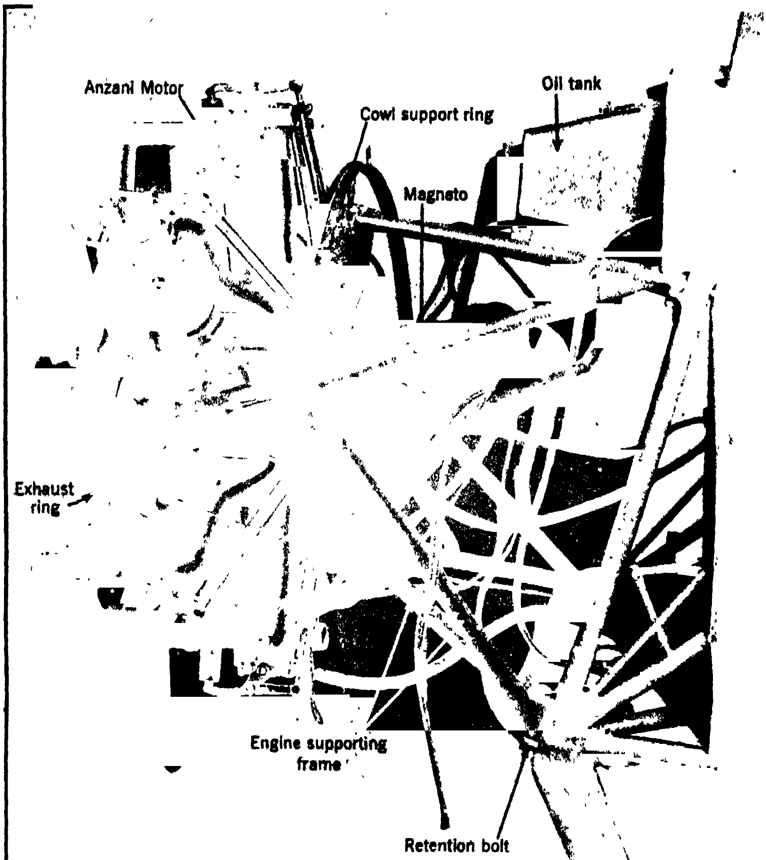


Fig. 494.—Front View of Airplane Fuselage Showing Typical Motor Mounting for Anzani, Ten-Cylinder Aviation Engine.

walls and cannot cause distortion. The piston pins (C) are of low carbon chrome-nickel steel having a thick section in the center and tapering toward the ends. The pins are case hardened, ground and polished. They float in the bushed head (D) of the connecting rod and the piston pin bosses in which they are kept from end motion by spring steel rings (E), which set into grooves in the boss boxes.

Valves and Rocker Arms.—The valves are of the flat in the head type, while in the new type motors they have a tulip shaped head. The valves

are so located that the propeller blast strikes the exhaust valve and the exhaust pipe first and the heat is carried over the inlet passages. The inlet headers (Q) are of aluminum castings; they are carried back of the cylinders so that they are kept hot in the coldest weather. The valve rocker arms are carried in a steel pedestal (N) which screws into a boss cast on the inlet passage in the cylinder. The long exhaust rocker (H) is placed above the shorter inlet rocker (I). The pivot pins are hollow case hardened bolts which hold sufficient bearing oil to lubricate the rocker arms for a long period. The valve springs are made of alloy steel with heavy retainers (G) and split annular retainer locks.

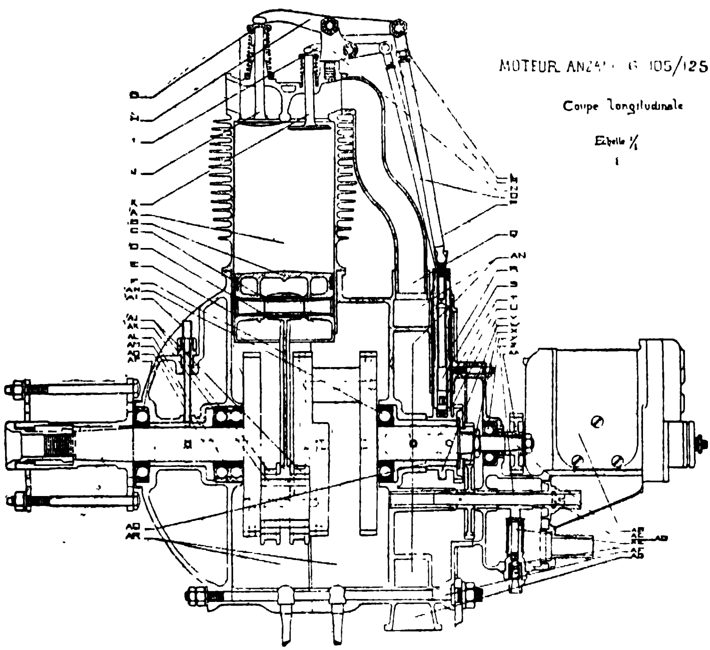


Fig. 495.—Sectional View Outlining Construction of the Six-Cylinder Anzani Motor Showing Simplicity of Valve Operating Gear and Generally Substantial Construction of the Engine.

Inlet Manifold.—The carburetor header (AG) fastens on to the lower part of the rear half of the crankcase so that it extends through the bottom of the airplane fuselage, eliminating fire risk. The inlet manifold (AN) is cast integral in the crankcase and carries the header pipes back of the cylinders. This disposition affords enough heat radiation from the cylinders to heat the mixture sufficiently to insure thorough vaporization without preheating the carburetor. On the 250 horsepower engine a double choke carburetor is used with two small manifolds and two sets of small header pipes leading to individual inlet valves (two per cylinder). It keeps the gas speeds high enough to insure perfect distribution; yet the combined

area is great enough to insure rapid and complete filling of the cylinders.

Magnetos.—The magnetos(AB), oil pump (AE) and tachometer drive (AD) are mounted on the camhousing cover plate, extending through the hole in the mounting plate into the fuselage where they are fully protected from the weather.

Connecting Rods.—The connecting rods (F), of the particular Anzani design, are of the same type which they have used since they built the first "Y" type engine in 1908. Numerous attempts have been made to make modified copies of these rods and Anzani has tried out every known scheme in experimental motors, but has retained a perfected form of the original rods, as this type has given the best satisfaction of any. The advantage of such disposition is quite apparent: All rods are the same length, the centers of all rods pass through the center of the crankpin, giving the same stroke for all cylinders, insuring equal timing. The assembly is easily taken down and repaired. It is very light and the large bearing areas make for long life. All wearing parts are quickly and cheaply replaced.

The crankpin bearing (AK) is a babbitt lined bronze bushing dovetailed at the joint. It floats on the crankpin and is held from end motion by fillets at the juncture of the crankpins and the cheeks of the throw. The diagonally cut slippers at the lower ends of the rods bear on the outside of this bushing and the rods are held in place and from end motion by two split bronze collars (AJ), which bear on the outside of the rod slippers. While the actual length of the slipper is about 60 degrees of the outside circumference of the bushing, the diagonal cut makes the effective length much greater and prevents any canting. The angular motion of the rods under the collars and over the bearing is very slight, as both the collars and the bushing float and the whole assembly bathes in oil. The life of the bearing and collars is very long; much longer, in fact, than any fixed liner-in rod or nest of rods. The joints of the collars are dovetailed and they are held together by alloy steel bolts. The connecting rods are chrome-nickel steel, machined and polished. The bronze piston pin bushing (C) is pressed into place and pinned with two bronze pins. In the three- and six-cylinder motors, there are three rods in each nest, while on the ten- and twenty-cylinder motors there are five.

Crankshaft.—The crankshaft (AO) is of the hollow type made in one piece, excepting the extension (AC), driving the cam and magnetos, which is screwed and pinned into the main shaft.

The center web of the crankshaft is undercut so as to bring the axis of the cylinders more closely together and to minimize the slight rocking couple which is the only unbalanced force present. A two-throw crank permits one set of unbalanced forces to neutralize the other, something which cannot be done with a single-throw crankshaft, regardless of the counterbalancing. The crankshafts are of chrome-nickel steel, machined and polished. They are counterbalanced very carefully, giving an extremely smooth and vibrationless engine. A two-throw shaft is used on the six- and ten-cylinder engines, while a single-throw counter-balanced crankshaft is used on the three-cylinder engine. The crankshaft is hollow and provides ample passage for oil lubrication. The oil is fed into the shaft through the

two main bearings (AM, AQ). Oil holes are provided in the crank throw pins and afford adequate lubrication to connecting rod bearings and collars.

The main bearings are of the same type as used on the original Anzani Aviation Engines, a combination of plain- and ball-bearings (AH, AL, AP). The main bearings proper (AM, AQ), are of the babbitt lined bronze type, the bronze shell combining a cup on the inner end in which a large ball thrust bearing (AL) is seated.

Distribution.—The valve mechanism of the Anzani is very simple, having a single piece inlet and exhaust cam (W). The timing gears, driven through intermediate gears (X), revolving at one-half camshaft speed, operates the entire valve mechanism which is clearly shown at Fig. 495. The inlet cam (V) consists of two narrow faced cams on opposite sides of the exhaust cam (W), the inlet tappet (T) being hollow and having a slot milled through it at the lower end leaving it fork shaped. Each tang of this fork rides on a face of the inlet cam, while the exhaust push rod (S) bears in the bore of the inlet tappet. The exhaust tappet has a roller (U) on the lower end, which extends through the slot in the inlet tappet and a slot milled in the bronze tappet guide (R), which prevents the whole assembly from turning. The exhaust tappet operates a single push rod (P) to the rocker arm, while the inlet tappet operates two smaller push rods (O) located on either side of the exhaust tappet to the inlet rocker arms. All of the push rods have adjustments at the upper end (LM). The intermediate gear (X) operates the oil pump (AE), the tachometer drive (AD) and the scavenger pump, which returns the oil from the lower oil collector tank to the nourrice tank. The magnetos are driven by a gear (AA) on the end of the crankshaft extension (AC).

Timing.—As in other operations connected with the servicing of the engine, the timing operation has been simplified to a high degree. No timing disc is used, No. 1 cylinder being provided with a timing hole in the head in which sets a screw, giving access to the combustion-chamber. The cam cover plate can be removed with the engine in place and the timing gears disengaged.

To time the engine remove the screw in No. 1 cylinder, put a piece of rod through the hole and bring the piston to top dead center. Put a scratch on the rod so that it registers with a division on a metric scale stood on the cylinder head beside the rod. Then turn the engine over in the direction of rotation until the mark on the rod has dropped four to five millimeters; then turn the cam so that the exhaust valve of No. 1 is just closing and mesh the gears. Replace the cover and turn the engine one complete turn; then with the piston on top dead center, turn the propeller against the direction of rotation eight millimeters on the scale for the 90x105 millimeter cylinder and turn the magneto so that the breaker points are just breaking, the brush in the distributor on No. 1 segment and mesh the gears.

Three-Cylinder

Horsepower, 30; weight, 110 pounds.
Bore, 90 millimeters; stroke, 120 millimeters; 1,800 r.p.m.
Horsepower, 35; weight, 132 pounds.
Bore, 105 millimeters; stroke, 120 millimeters; 1,800 r.p.m.

Timing—

Exhaust valves open eighteen-twenty millimeters before bottom dead center.

Inlet valves open four-five millimeters after top dead center.

Spark, six-eight millimeters before top dead center.

Six-Cylinder

Horsepower, 60; weight, 165 pounds.

Bore, 90; stroke, 120; 1,600 r.p.m.

Timing—

Exhaust valves open eighteen-twenty millimeters before bottom dead center.

Inlet valves open four-five millimeters after top dead center.

Spark, six-eight millimeters before top dead center.

Horsepower, 80; weight, 215 pounds.

Bore, 105; stroke, 125; 1,600 r.p.m.

Timing—

Exhaust valves open twenty-twenty-five millimeters before bottom dead center.

Inlet valves open four-five millimeters after top dead center.

Spark, six-eight before top dead center.

Ten-Cylinder

Horsepower, 120; weight, 320 pounds.

Bore, 105; stroke, 140; 1,600 r.p.m.

Timing—

Exhaust valves open twenty-twenty-five millimeters before bottom dead center.

Inlet valves open four-five millimeters after top dead center.

Spark, six-eight before top dead center.

The clearance between the exhaust rocker arms and valve stem should be .018 inch to .020 inch and the inlet rockers are adjusted so as to open as the exhaust closes, which should give about the same clearance. Such clearances should be measured when motor is cold.

Anzani Engine Care and Operation.—The following rules should be carried out after every long flight and if maximum service and long life is expected from the engine after every flight: When the engine is still warm, take off all sparkplugs and clean them with gasoline and a stiff brush, at the same time check each electrode gap. Before replacing sparkplugs squirt kerosene into the cylinders, which will help remove carbon, burnt oil and will prevent gumming of piston rings. The propeller should be turned over swiftly a few times, thus throwing out excess kerosene from the cylinders. Likewise, kerosene squirted on valve stems while motor is still warm, prevents sticking valves. Magneto distributors and brushes should be examined after each flight. The distributor should be kept clean from grit and oil. The breaker points should be checked with a .020 inch gauge and the cleanliness of the points should be ascertained. When the engine is started, it should be run for a little while at closed throttle. The fact that an air-cooled engine warms up rapidly is no excuse for throwing a full load on a cold engine. Every engine should be idled with closed throttle or nearly closed throttle for several minutes so as to afford ade-

quate distribution of oil throughout the motor before a load is thrown on the bearing. **Do not accelerate engine until it has been warmed up thoroughly.**

To Stop Engine.—The proper way to stop the motor is to shut off the gasoline supply and let the motor die out from the charge held in the carburetor bowl. If it is inconvenient to do so, it is advisable to let the motor idle for five minutes or so before cutting the switch, this will not only give the valves a chance to cool down, but distribute oil through the inside of motor so as to have the parts well lubricated for the next start. More airplane motors are harmed through neglect of these perfectly simple rules than any other cause. Improper stopping is the greatest source of valve trouble in aviation motors. Proper lubrication of all moving parts, such as rocker arm pins, valve stems, etc., should not be overlooked, the rocker arm pins are left hollow on purpose and these should be filled with a heavy oil every time the motor is used so as to insure adequate lubrication of the rocker arms.

STANDARD ANZANI ADJUSTMENTS

Sparkplugs.—It is advisable to keep a close check on the spark gap. The best plug for Anzani motors are the BG and the AC, although any standard aviation mica body plug can be used with satisfaction. Sparkplugs should have .018 inch clearance between electrodes.

Magneto Breaker Points.—Gap between breaker point when fully open should be of .020 inch. It is possible to obtain better results if the breaker gap is reduced to .018 inch. The makers do not recommend one to change the gap distance, unless the motor has a tendency to miss high speed; only then should the reduced gap distance be tried. Great care should be also taken to see that the small rocker arm on which is mounted one of the platinum points should move freely on its axis, if it is found that it has a tendency to bind, carborundum cloth may be used to polish the axis lightly.

Valve Clearances.—Inlet and exhaust valves should be set respectively at a clearance of .018 inch and .020 inch between end of rocker and valve stem.

Lubrication System.—For motors provided with rotary pressure pump: When the motor is new or under ten to fifteen hours of running time, the bypass of the pump must be pointing to the letter "O" as stamped on the cover; it is then wide open, feeding a full supply of oil. Leave it this way until the engine is well run in; after this, shut it off slightly towards the letter "F" so that no oil overflows out but enough to properly lubricate the engine, the oil gauge should read from five to six pounds, with a cold motor and not less than from two to three pounds with a warm motor. For the plunger type pump, if pump is found to feed too much oil, a spacer gasket of $\frac{1}{16}$ inch can be inserted under the plunger cover.

Insufficient Lubrication.—If through oversight or any other cause, the engine does not receive sufficient lubrication and begins to heat and pound, it should be stopped immediately. After allowing engine to cool, the operation of the oil pump should be ascertained and half a gallon of oil should be poured in a crankcase through the breather holes, but not before the exact cause of this sudden overheating has been found and corrected. It is also advisable, in this case, to disconnect the oil leads to the crankcase

and using an oil gun to force a quantity of oil into each oil lead, turning the motor over slowly by hand all of the time so as to fill the crankshaft leads and bearings with oil.

Carburetor.—Care should be taken to ascertain if all nozzles and jets are tight in the carburetor. It is a wise practice before each flight to take off the well cover nuts, to ascertain that no water has collected, as this is the lowest point in the carburetor. A very few drops of water lodged in the bottom of the unions will suffice to produce transient difficulties in carburetion. Assuming the amount of water to be small, the trouble may be remedied by taking out the two hexagon nuts under the jets and emptying the carburetor.

Ignition System.—It is most important that after every long flight, the distributor block be detached and wiped off with a soft cloth. The carbon brush leaves a deposit where it runs between the contact points which often enables the spark to jump across from one terminal to the other, thus causing the motor to misfire and run roughly. If this deposit cannot be removed with a cloth dipped in gasoline, a very fine emery cloth can be used to polish the distributor lightly. The dust resulting from this polishing must be wiped off carefully with a rag.

Propeller.—It is of great importance that the propeller be tracked to one-eighth of an inch and a check should be kept on its tracking every ten hours of flying time. If it is not true, excessive vibration will result. Anzani propeller hubs are put on very tightly on the motors, after being lapped and in consequence there is an absolute metal to metal bearing between the hub and the crankshaft cone. When the propeller hub is withdrawn, the metal in the hub and on the crankshaft cone is sometimes torn. When the hub is replaced, instead of fitting tightly on the shaft, the torn metal on the shaft rests on the torn metal on the hub and after a few hours running, the hub becomes loose and is liable to break the keyway. It is not necessary to withdraw the hub to apply or remove the propeller, as the engines are of the fixed hub type and the hub should only be withdrawn in case of a complete engine teardown. After the hub has been withdrawn, it should be lapped carefully on the crankshaft before setting back in place.

Crankcase.—Care should be taken that the crankcase bolts should not be tightened with too great strength, as a certain heat expansion takes place and if the bolts are tightened too much, the strain on the crankcase is liable to cause it to split. When the motor arrives from the factory, no tightening of the bolts should take place as they have been carefully tightened and safetied with counter nuts before leaving factory. Crankcase end play should be at least .018 inch.

Preparation to Start Engine.—Before starting the motor for the first time, it is a good plan to take off the oil pipes where they join the crankcase and force oil down these openings with an oil gun while the motor is being turned slowly by hand. After a quantity of oil has been forced into the oil ways, the connection should be tightened, the tank should be filled. With the plunger type pump a supply of ½ gallon must be poured in the crankcase through breather pipes. Always fill gasoline tank through a strainer of chamois skin, this will afford clean gasoline supply, the strainer catching water and other impurities. Rocker-arms, rocker-arm pins and

valve stems should be thoroughly lubricated with heavy oil. Magneto should be given two or three drops of oil every five hours of running.

After all the parts are oiled and the tank filled, the following must be looked after before starting the motor: See that magnetos are properly grounded. See that magneto bolts are tight and safety wired. See that magneto cables are in good condition. See if the two intake push rods are securely bound together with safety wire, the absence of such causing floating and breaking of push rod adjustable eyelets. They must be bound together just below the adjustable eyelets. See if rocker arm tappets have the proper clearance. See that oil and gasoline lines are in perfect condition. See that propeller bolts are safety wired. Every month all cylinder hold down nuts should be gone over to ascertain whether they are tight. The proper way to tighten these nuts is to pull them down tight and then unscrew one-third of a turn, thus allowing for heat expansion. It is important not to forget to recotter. After making sure that above rules have been observed, the compression of cylinders should be tested by turning propeller slowly.

Starting the Engine.—Do not forget to short both magnetos. Open throttle slightly, flush the carburetor and with the switch "off" turn propeller over several times to draw in a charge, turn the ignition switch on "contact" and pull propeller swiftly over compression. This should start the motor immediately.

Failure to start the engine might be caused by the following conditions: In cold weather the carburetor should be primed well. In warm weather it should only be primed slightly. After the engine has once been started, only a slight priming is necessary in order to insure quick starting.

If one makes several attempts to start the engine as above directed and does not succeed, it is advisable to inspect the ignition system, checking first: That all cable terminals are in their proper places and secured. That the breaker points have the proper spacing. That the distributor heads are clean and free from oil and carbon deposit. That the distributor brush does not bind. That ground wires are not shortened in any place. That magnetos deliver a spark when turned over. If the sparkplugs have not been cleaned as advised, they should be removed and cleaned thoroughly. If the ignition system is found to be satisfactory, the trouble must be in the carburetion. The carburetion float may be punctured and filled with gasoline. The needle valve might not work freely or obstruction between valve and seat might prevent its proper action. The gasoline line might be filled with water or clogged with impurities. If the jets are found to be clogged, do not clean same with wire or sharp instruments, this practice enlarges the metered holes and supplies an improper quantity of gasoline. They should be blown out with compressed air. The engine might have been flooded by excessive priming. In this case, with the switch "off," open throttle wide and turn over propeller swiftly in the opposite way of rotation a few revolutions, then close throttle and open switch, the motor ought to start without any additional priming.

Decrease in Engine Efficiency.—After the engine has been continuously in service for a certain length of time, it may decrease in its r.p.m.; there are different causes for this: primarily the valves need grinding; they

ought to be ground after an average of 90 to 100 hours of running time. The magneto distributor might be dirty, the carbon brush running between distributing points will leave a deposit, this fine dust will allow sparks to jump from one terminal to the other causing the motor to preignite and run roughly; the distributor head must be removed and cleaned as previously suggested. Through the use of low test commercial gasoline, the carbon deposit in the cylinder heads might prove to be a source of pre-ignition, pounding, vibration and loss of compression. It should be removed by scraping only.

Gravity Feed Gasoline Supply.—If gravity feed gasoline supply tank is used as per the new Department of Commerce regulation, it is advisable that the drop between the lowest portion of the gasoline tank to the upper part of the carburetor or float chamber should not be less than 24 inches. If gravity tank is used and the engine runs satisfactorily at low speed, but cuts out at high speed, the trouble is undoubtedly due to insufficient height of tank, the size of gasoline line or air hole in tank. Care should be taken to keep air hole in tank cap free of any obstruction.

Disassembling the Engine.—The actual operation of dismounting cylinders of the Anzani engine has been made so simple that it can be done in less than fifteen minutes for the three cylinders and 20 to 25 minutes for the six. To remove cylinders from crankcase for valve grinding or inspection, first unscrew the studs holding the exhaust pipes or manifold, then remove cotter pins and unscrew the two nuts on the hold down rods of each cylinder. The cylinder can be removed without taking off the intake pipe which has a sliding fit in the crankcase, but after the two inlet push rods eyelets have been disconnected from cam follower rod by removing the stop ring, or in other motors both cotter pin and stop ring. When the cylinder is ready to be pulled out of the crankcase, care should be taken to avoid having the piston and rod fall against the crankcase or the next cylinder as it is liable to throw them out of line. The cam cover plate can be removed for inspection without taking the motor off its mounting.

The propeller should be mounted on the hub in the usual fashion; that is to say that the axis of the blades should be set one bolt ahead in the way of rotation. This will afford easier starting by placing the compression at the easiest and safest point for cranking.

Valve Grinding.—Take out the valve and clean it thoroughly, also noting whether or not the stem is clean, or otherwise in good condition. Replace the valve and grind by rotating it back and forth, the grinding paste being between the valve and the seat. Care should be taken to raise the valve from its seat frequently, while grinding. This prevents making a groove in the seat. It is essential after the valves are ground to clean the entire cylinder with gasoline, wiping same with a soft, clean rag, making sure all the grinding paste has been removed. The sides of the cylinder walls should be oiled with clean oil before the cylinders are slipped over pistons and put back into place.

Cleaning Pistons.—When slipping off the cylinders, care should be taken to steady the pistons, so they will not fall over after cylinder is removed, which might result in distorting their shape. To remove the piston rings three or four strips of $\frac{1}{32}$ inch spring steel should be used. These should

be slipped around the ring until it is entirely free of the groove, after which it can be slipped off quite readily. Clean slots by scraping, taking care not to scratch the metal. Use cloth moistened with gasoline to clean the surfaces after carbon is removed. If there are any bright spots on the outside walls of the piston, it shows an undue amount of friction is taking place at that point. A very fine file can be used to touch up these spots. (This should be attempted only by skilled or thoroughly competent mechanics.) In reassembling the rings in their respective grooves, they should be free to move around without binding at any place. Oil the pistons, rings, and grooves before assembling pistons in cylinders.

If Anzani engine fails to start it may be due to any of the following causes: 1. Lack of gasoline. (a) Examine tank. (b) Examine shut off cock. (c) Examine filter. (d) Examine piping. (e) Examine hose connections. (f) Examine carburetor float valve. 2. Ignition ground-wire improperly connected. 3. Engine primed too heavily. Rotate engine backward with throttle wide open ten or twelve revolutions to clear the excess gas in cylinders. 4. Engine insufficiently primed. 5. Ignition wire improperly connected. 6. Ignition incorrectly timed. 7. Water in carburetor. 8. Throttle too wide open. 9. Throttle not open wide enough. 10. Valves improperly timed. 11. Air leak in intake manifold.

If Engine Stops.—This may be due to 1. Lack of gasoline. 2. Water in carburetor. 3. Ignition trouble. 4. Engine overheated. 5. Lack of lubrication.

If Engine Misses.—Irregular operation due to misfiring may be caused by 1. Sparkplug loose or defective. (A missing cylinder can be easily found after stopping motor by putting the hand on the cylinder cooling flanges. The cold cylinder is the one which does not fire.) 2. Water or dirt in carburetor. 3. Breaker points of magneto binding or dirty. 4. Dirt or moisture in distributor. 5. Piston rings leaking oil, thereby fouling sparkplugs. 6. Valve spring broken. 7. Unequal compression due to (a) Valve stem sticking. (b) Valve seat caked with carbon. (c) Valve warped. (d) Valve broken.

If Anzani Engine Fails to Develop Power.—The following are the main reasons for reduced power output: 1. One or more cylinders missing. 2. Insufficient throttle opening (at carburetor). 3. Insufficient spark advance. (a) Piping or shut off cock too small. (b) Obstruction in piping. 4. Insufficient gasoline supply. 5. Gasoline tank air bound. 6. Improper carburetor adjustment. 7. Improper lubrication. 8. Engine overheated. 9. Water in gasoline. 10. Air leak in intake manifold. 11. Excessive carbon (preignition). 12. Valves leaking compression. 13. Piston rings leaking compression.

If Anzani Engine Overheats.—Check over the following: 1. Insufficient lubrication. (a) Empty oil tank. (b) Obstruction in oil lines. (c) Defective priming of oil pump. (d) Oil valve seat obstructed by impurities. 2. Improper carburetor adjustment. 3. Broken piston rings. 4. Excessive carbon. 5. Poor gasoline.

Try one thing at a time and in the order suggested. Once trouble is located, the remedy should be easy to apply. Correct fault immediately. To insure maximum service, the engine should be inspected thoroughly,

systematically at regular intervals. Some standard form of inspection should be adopted, adhered to, not only for engine inspection, but also for all connections, piping, tanks and motor-bed fixation. The suggestions given for trouble shooting and repair of components in other chapters can also be used for reference in connection with locating Anzani engine troubles and repairing them.

Salmson Air-Cooled Engines.—The Société des Moteurs Salmson was formed at the beginning of 1913 for the manufacture of stationary radial type aero-engines, Canton-Unné system, following experiments since 1908. The qualities of these engines, demonstrated by the official trials effected at Chalais-Meudon and by the successes gained in aeronautical tests in which they participated, at once assured the prosperity of the company. From 1914 to 1918 the Société des Moteurs Salmson developed considerably. The workshops for mechanical constructions were greatly enlarged and important forges, foundries, coppersmiths' and carpenters' shops, airplane and magneto factories were installed. The works covering an area of 72,000 square meters enabled the

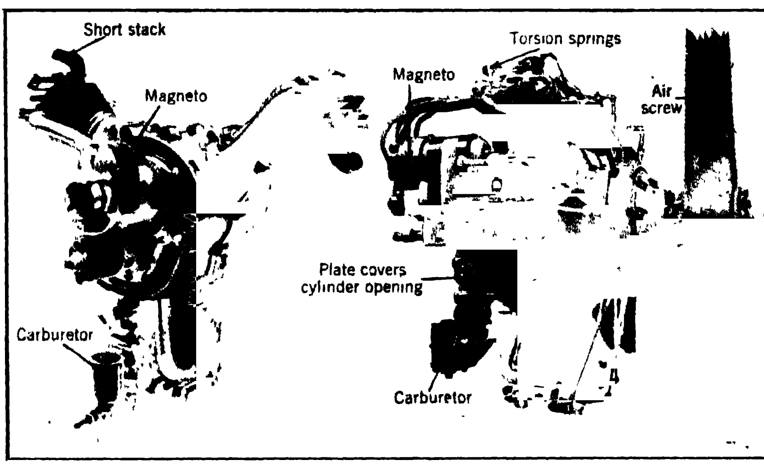


Fig. 495A.—Two Models of Salmson Air-Cooled Engine for Light Plane Use. The Twelve Horsepower is Shown at the Left and the 25 Horsepower Six-Cylinder Model Shown at the Right.

French Air Board to take, in November, 1918, a monthly delivery of: 200 complete airplanes, 650 aero-engines, 1,600 aero-magnetos. The importance of their output, their extensive works especially equipped for the construction of aeronautical materials, their research department, laboratories and technical staff have made the Société des Moteurs Salmson one of the most important aviation firms in France.

Since this period, they have unceasingly pursued their technical efforts in connection with the stationary radial-engine, remarkable for its resistance, perfect balance at all speeds, simple oiling system, easy method of entering and mounting on the plane and its accessibility. Other important

points are the facility with which it is kept in order and the smallness of the unit considering its high power capability. The Société des Moteurs Salmson was therefore the first to design a complete range of new types.

On the other hand, the Société des Moteurs Salmson have not discontinued their experimental work on the water-cooled engine and have constructed the CM9 type—260 horsepower and the CM18 type—500 horsepower which rapidly proved their exceptional endurance qualities: the CM9—260 horsepower by 300 hours tests effected at the official laboratories of Chalais-Meudon, the CM18—500 horsepower by two tests of 150 hours each accomplished in fifteen periods of ten consecutive hours, without the replacement of any part or accessory.

The Société des Moteurs Salmson manufacture a complete line of different types of engines which range as follows:

Air-Cooled Engines

Types	*Nominal Power*	*R.P.M*
AD 3	12 HP.	1,800
AD 6	25 HP.	1,900
AD 9	40 HP.	2,000
AC 5	65 HP.	1,800
AC 7	95 HP.	1,800
AC 9	120 HP.	1,800
AB 9	230 HP.	1,700
AB 18	460 HP.	1,700
	Water-Cooled Engines	
CM 9	260 HP.	1,650
CM 18	500 HP.	1,650

The AD3 twelve horsepower engine has all its principal parts such as cylinders, connecting rods, pistons, valves, valve-springs, rockers, etc., absolutely interchangeable with the corresponding parts of the engines AD9 40 horsepower and AD6 25 horsepower, thus allowing a very noteworthy standardization for these three engines.

The AD 3 twelve horsepower, which is shown at Fig. 495 A, engine is of the stationary type, radial, air-cooled, four-stroke, having three cylinders. Bore: 70 millimeters; Stroke: 86 millimeters; Capacity: 993 cubic centimeters; Compression ratio: 5.6 to 1. The engine is suspended by rear crankcase.

R.P.M.	*Nominal Power*	*Power on Rising*
1,800	12 HP.	14 HP.
2,400	15 HP.	18 HP.

At 1,800 r.p.m. developing twelve horsepower: Fuel and oil consumption figures are:

	Aviation Petrol	*Castor Oil*
Per hour	3 kgs.	240 grs.
Per horsepower hour	250 grs.	20 grs.

The engine dimensions are: Length: 570 millimeters; Maximum radius: 320 millimeters. Engine complete in running order with propeller hub, carburetor and magneto, without silencer weighs 34 kilograms. The AD 3 en-engine has its propeller fitted direct to the crankshaft and revolves in a clockwise direction for an observer facing the propeller. A single induction pipe in the rear crankcase feeds each cylinder and receives the gases from the carburetor fitted with a correcter. Ignition is by Salmson magneto and one sparking plug for each cylinder.

Lubrication is insured by pump with return to oil tank for oil recovered from crankcase.

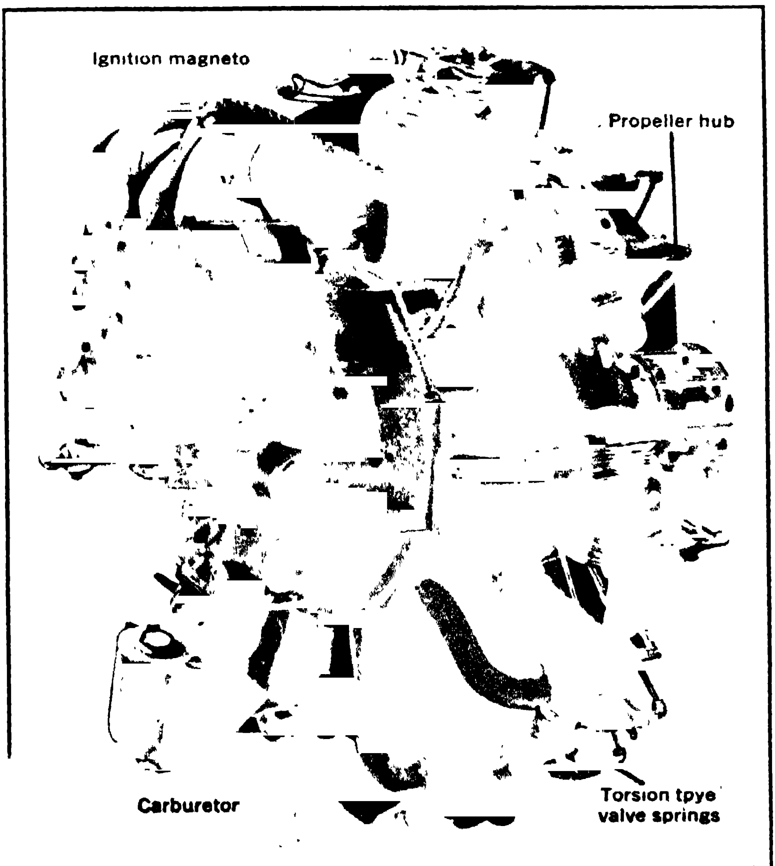


Fig. 495B.—Nine-Cylinder Salmson 40 Horsepower Air-Cooled Engine.

The AD 6 air-cooled engine, designed for use on the light touring plane, was registered in June, 1925, at the nominal power of 25 horsepower at 1,900 r.p.m. As the low-powered engine is not sufficiently in demand to justify the building of an entirely new type of engine between twelve and

40 horsepower, the Société des Moteurs Salmson simply decided on the production of their AD6 25-horsepower engine. This they derived from their nine cylinder AD9 40-horsepower engine, the characteristics of which will be found elsewhere, by suppressing on this engine three connecting rods, three pistons, three cylinders and three sets of valve gear, preserving however, at the same time a perfect regularity of cycle. The above engine fitted to a Gateau light plane, competed successfully at the meeting of Vauville in July-August, 1925. It can be adapted with the greatest ease to any light plane. The AD6 25-horsepower engine has all its principal parts, such as cylinders, connecting rods, pistons, valves, valve-springs, rockers, etc. absolutely interchangeable with the corresponding parts of the engines AD3 twelve-horsepower and AD9 40-horsepower, thus allowing a very noteworthy standardization for these three engines. This engine is shown at right of the cut Fig. 495 A.

The AD6 25-horsepower engine is of the stationary radial, air-cooled, four-stroke type, having six cylinders. Bore: 70 millimeters; Stroke: 86 millimeters; Capacity: 1.986 cubic centimeters; Compression ratio: 5.6 to 1; Suspended by rear crankcase. Nominal power at 1,900 r.p.m. 25 horsepower.

At 1,900 r.p.m. developing 25 horsepower: Fuel consumption and oil used is

	Aviation Petrol	*Castor Oil*
Per hour	6 kgs. 25	500 grs.
Per horsepower hour	250 grs.	20 grs.

The length is 690 millimeters. Maximum radius is 320 millimeters. Engine complete in running order with propeller hub, carburetor and magneto, without silencer weighs 60 kilograms. The AD6 engine has its propeller fitted direct to the crankshaft and revolves in a clockwise direction for an observer facing the propeller. A single induction pipe in the rear crankcase feeds each cylinder and receives the gases from the carburetor fitted with a correcter. Ignition is by Salmson magneto GG9 and two sparking plugs per cylinder. Oiling is insured by pump with return to oil tank of oil recovered from crankcase.

The AD9 40-horsepower, shown at Fig. 495 B, engine is of the stationary radial, air-cooled, four-stroke having nine cylinders. Bore: 70 millimeters. Stroke: 86 millimeters. Capacity: 2,979 cubic centimeters. Compression ratio: 5.6. The engine is suspended by rear crankcase.

Nominal power at 2,000 r.p.m.: 40 horsepower.

Power on rising at 2,000 r.p.m.: 46 horsepower.

At 2,000 r.p.m. developing 40 horsepower the fuel and oil consumption is:

	Aviation Petrol	*Castor Oil*
Per hour	9 kgs. 8	800 grs.
Per horsepower hour	245 grs.	20 grs.

The engine dimensions are: Length: 690 millimeters. Diameter: 630 millimeters. Engine complete in running order with propeller hub, carburetor

and magneto, without silencer weighs 75 kilograms. The AD 9 engine has its propeller fitted direct to the crankshaft and revolves in a clockwise direction for an observer facing the propeller. A single induction pipe in the rear crankcase feeds each cylinder and receives the gases from the carburetor fitted with a corrector. Ignition is by Salmson magneto GG 9 and one sparking plug per cylinder. Lubrication is insured by pump with return to oil tank of oil recovered from crankcase.

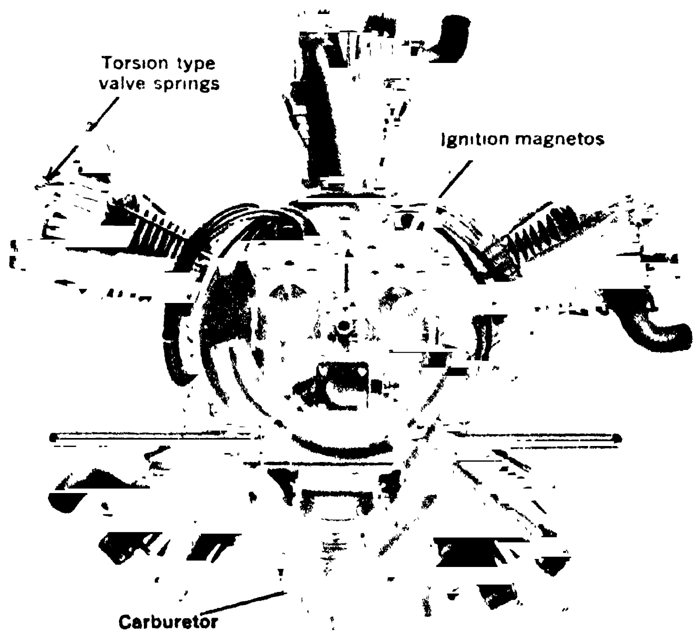


Fig. 495C.—Rear View of Salmson Five-Cylinder, 65 Horsepower Airplane Engine.

The AC 5 engine of 65 horsepower, shown at Fig. 495 C, is of the stationary radial, air-cooled, four-stroke type having five cylinders. Bore: 100 millimeters. Stroke: 130 millimeters. The cubic capacity: 5,105 cubic centimeters. Compression ratio: 5 to 5.4 to 1. The engine is suspended by rear crankcase. Nominal power at 1,800 r.p.m.: 65 horsepower cylinder in the wind.

At 1,800 r.p.m. developing 65 horsepower, the fuel and oil consumption is:

	Aviation Petrol	*Castor Oil*
Per hour	15 kgs. 925	1 kg. 300
Per horsepower hours	245 grs.	20 grs.

The engine length: 820 millimeters. Diameter: 940 millimeters.

The engine weighs complete in running order with magnetos, carburetor, propeller hub: 110 kilograms or 242 pounds.

The AC 5 engine is adapted for use as a tractor or pusher, the propeller being mounted direct on the crankshaft which is fitted with double thrust bearings for this purpose. The engine revolves in a clockwise direction for an observer facing the propeller. Although easily started with the propeller by means of a starter magneto, the engine is provided with a distributor fitted at the rear allowing the engine to be started under compression. The five steel cylinders fitted with aluminum-finned jackets are fixed singly to the crankcase by studs, and therefore can be removed independently of each other. The master connecting rod, which is balanced and made of special steel, revolves on a white metal lined central bearing of large dimension. The crankshaft of nickel-chrome steel carries counter weights so arranged as to balance the whole group of connecting rods in all their positions and at all speeds.

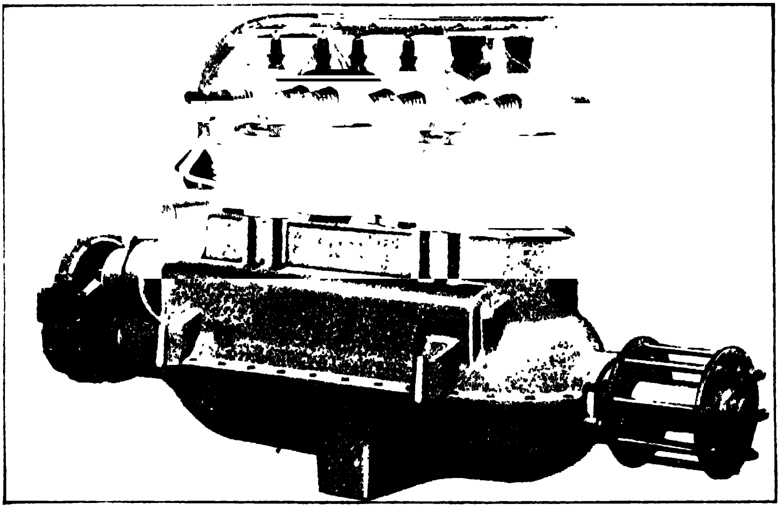


Fig. 495D.—The Cameron Four-In-Line Air-Cooled 60 Hp. Engine.

The distribution or valve action operated by a circular cam acts on the valves through roller tappets, rockers and adjustable rods. A single inlet pipe located in rear crankcase feeds each cylinder and receives the gasses from a muffler coupled to the carburetor which is fitted with an automatic altimetric corrector. Ignition is by two Salmson magnetos H 5-20 and two sparking plugs of eighteen millimeters, 1.5 pitch, per cylinder. Oiling is insured by pump with return to oil tank of oil recovered from crankcase. A circular manifold forming a silencer and provided with clearing pipes is fitted on request. Besides the starting distributor the engine carries at its rear standarized fittings for a revolution counter and two petrol pumps.

Cameron 60 Hp. Four-in-Line Engine.—The illustration at Fig. 495 D shows a Cameron four-cylinder vertical motor intended for light one- and two-place airplanes. It is claimed that this type of construction is well adapted for a good streamline installation. This motor uses the same system of cylinder construction and valve actuation that is found in the regular seven-cylinder radial engine. There are four valves per cylinder, opposite each other in the head so that the cool incoming charge from the inlet valves sweeps directly past the points of the sparkplugs, cooling them and also cools the exhaust valve heads. It is also claimed that this system of valve location prevents pre-ignition and detonation at high compression. It also makes the use of exceptionally large valves possible. The valve springs are horizontal and project into the air stream so that proper cooling is assured at all times. The indirect actuation of the valves by the use of intermediate sliding members from vertical rocker shafts give a direct horizontal thrust which eliminates any possibility of abnormal wear on the valve stem guides because of angular pressure of the valve stems. The connecting-rods are of dural alloy, the pistons and crankcase are of aluminum; the cylinders with their integral heads are of nickel-iron and all steel parts are of high strength, heat-treated steels especially developed for the purpose.

SPECIFICATIONS

Type	Four-in-Line Air Cooled
Number of Cylinders	Four
Bore	4.125 inches
Stroke	4.75 inches
Displacement	254 cubic inches
Compression Ratio	
For Standard Gas	5:2:1
For Aviation Gas	6 0 1
Hp. at Sea-level with standard gas	60 Hp. at 1800 R P.M.
Dry weight	180 pounds
Height	27.75 inches
Width	14 inches
Length over all	39.125 inches

Rover Air-Cooled Engine.—The Rover is a four-cylinder-in-line, inverted, air-cooled engine of the four cycle type, following conventional practices and of simple and rugged construction. A bore of 3⅞ inches and a stroke of five inches give a piston displacement of 236 cubic inches, the normal b.hp. being 55-60 at 1,800 r.p.m. The compression ratio is five to one. The weight of the engine complete less starter is 210 pounds. It is made by the Michigan Screw Company, Lansing, Mich.

The crankcase is a deep, well ribbed aluminum casting with webs providing support between each cylinder for both crankshaft and camshaft bearings. Integral passages are formed within the casting for the full pressure oiling system to all bearings. Four pads are provided on the sides of the casting for mounting. The crankcase is covered by a light, easily removable cover, which carries the breather on top at the rear as shown at Fig. 495 E. All accessories are mounted on the timing gear cover at the rear and may be removed as a unit as shown at Fig. 495 F.

A single camshaft with integral cams, is supported in the crankcase and is driven by simple spur gearing from the rear end of which the tachometer drive is directly connected. Conventional push rod and rocker arm valve action is employed with two springs for each valve.

The five bearing crankshaft, which is of ample proportions and carefully balanced, is mounted in steel backed babbitted bearings. Crankpins and journals are bored out for lightness and oil is led to the crankpins through small

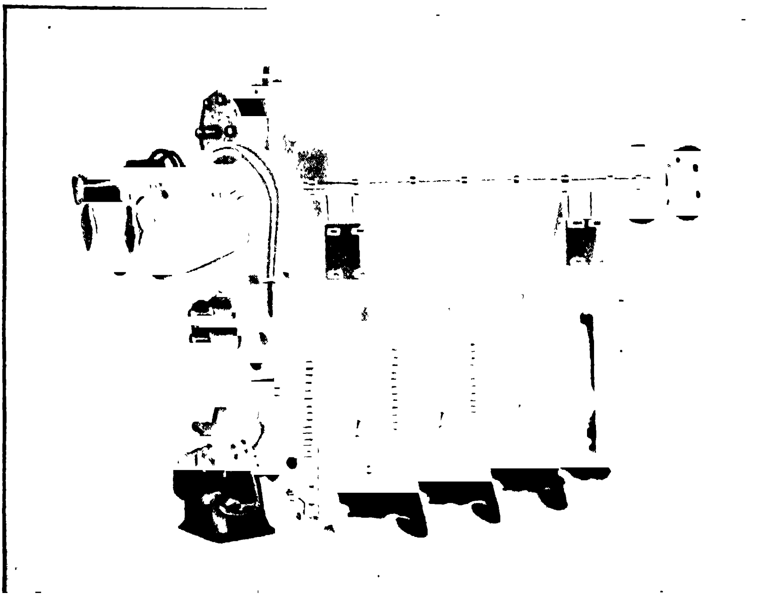


Fig. 495E.—Rear Quarter View of the Rover Four-In-Line Inverted Engine.

steel tubes expanded into position. Propeller end thrust is taken by a deep grooved ball bearing. Connecting rods are duralumin forgings of H section with bronze bushed piston pin ends and babbitted big end bearings.

The cylinders are integral chrome-nickel iron castings, having a spherical form of combustion chamber with valves inclined at an angle of 25 degrees. The skirts of the cylinders extend well into the crankcase, preventing oil from entering their open ends due to inverted running. The design has been arranged so that any one cylinder may be removed without disturbing any of the remaining ones.

The die-cast aluminum pistons have three rings at the top and one scraper ring at the bottom, also, a full floating piston pin using bronze end plugs.

Outside Tank Oil.—All oil is carried in an outside tank and a conventional two gear pressure pump delivers oil to all bearings under a pressure of 35-40 pounds, means being provided for pressure regulation. A three gear scavenger pump drains each end of the crankcase independently and returns the oil to the tank. A large oil filtering screen is arranged at the side of the engine where it may be easily removed for cleaning.

Dual ignition is provided, using two flange mounted Scintilla Magnetos,

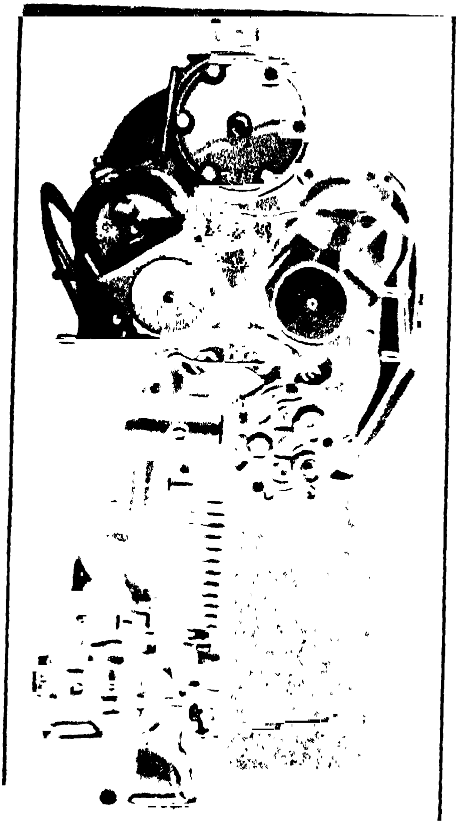


Fig. 495F.—Rear View of Rover Engine Showing Installation of Accessories.

one being provided with an automatic impulse coupling which is inclosed within the engine to insure easy starting under all conditions.

The Stromberg NA-R3 carburetor, fitted with altitude adjustment and priming device, is arranged at the rear with manifolding along the side keeping the width to a minimum to simplify the cowling of the engine in the plane. Provision is made for a standard hand or electric starter.

QUESTIONS FOR REVIEW

1. Describe cam construction and cam speed for various types of LeBlond engines.
2. Outline cylinder construction of Warner "Scarab" engine.
3. What is the Super-Rhone engine?
4. In what way is the cylinder construction of the ASSO 80T engine unusual?
5. Describe cylinder construction of Anzani engines.
6. What is the connecting rod arrangement on Anzani engines?
7. What are the Anzani engine valve clearances?
8. What is an important feature of Salmson engines?
9. Describe valve operation of Cameron four-cylinder engine.
10. What is the distinctive feature of the Rover engine?

CHAPTER XXX

THE A. D. C. CIRRUS ENGINE

Features of Cirrus Engine—Specifications—General Description—Valves and Valve Gear—Pistons and Connecting Rods—Crankshaft—Crankcase—Camshaft—Induction Manifold—Lubrication—Oil Pressure—Ignition—Carburetor—Dismantling Engine—Cleaning Parts—Examination and Assembly of Engine—Instructions for Valve Timing—To Time Magnetos—Running Instructions—Cirrus Engine Troubles—Maintenance—Table of Clearances.

The Cirrus Mark II engine, manufactured by the A.D.C. Aircraft, Ltd., London, England, has in the past several years established an enviable record. The engine has been supplied to all of the light airplane clubs subsidized by the British Air Ministry, and, in addition, the engines have been used on flights from England to India and to South Africa as well as on air tours in Europe and Australia. Cirrus engined planes claim the light airplane altitude record, the light plane nonstop record, and the distance record for a pilot unaccompanied. The engines have also been in the winning planes of the King's Cup Air Races for the past two years; winning both first and second place this year.

Features of Cirrus Engine.—The Cirrus is a four-cylinder in line, direct drive, vertical, air-cooled engine. It is very simple in construction with all of the accessories on the right side which is shown at Fig. 497. In May, 1925, the Cirrus engine passed its first 100-hour test and has been since improved until it is now rated at 78 horsepower at 1,800 r.p.m. It develops a maximum of 84 horsepower at 2,000 r.p.m. and weighs 280 pounds. The engine has a wet sump and, therefore, when considering the weight per horsepower it should be realized that the weight of an oil tank, pipe lines, collector ring, etc., is eliminated. The Cirrus engine was designed by Maj. Frank B. Halford principally for use in the De Havilland "Moth" low-powered two-place biplane. Low cost, ease of maintenance and reliability were the main considerations. It has also been used in the Avro Avian and other light airplanes.

The new A.D.C. "Cirrus" (Mark II) engine has been designed to meet the special requirements of light aircraft, and, as a result of experience with the earlier "Cirrus" (Mark II) engine, new features have been incorporated in the design of the Mark II type which increase the reliability and lessen the cost of maintenance. The following description and illustrations will give a clear impression of the simplicity and orthodox nature of the engine's design. There are no complicated fittings or other features requiring expert attention. Special instructions or experience are not essential, and the engine can be readily understood and maintained in perfect running order by the average owner-driver or motor mechanic. In this respect "Cirrus" engines are of great value. As plans are being made for the early manufacture of this engine in the United States, it is believed the complete instructions for operation and the description furnished by the

makers will be of interest because it will undoubtedly be used in a number of airplanes of American construction. The simplicity of construction and robustness of design will be apparent from study of the illustrations, Figs. 496 to 498 inclusive.

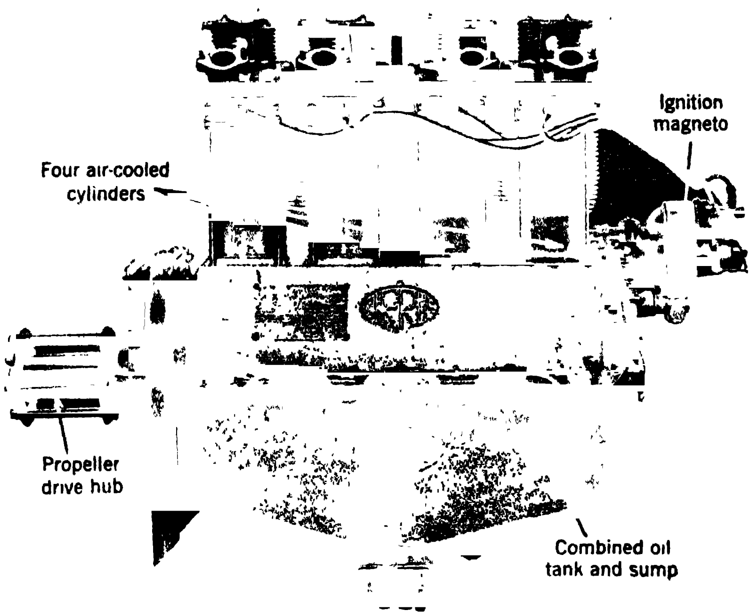


Fig. 496.—A.D.C Cirrus (British) Mark II Aviation Engine, One of the Most Popular Engines for Light Airplanes.

SPECIFICATIONS

Type (Vertical)	4-cylinder in-line
Bore	110 m/m
Stroke	130 m/m.
Total swept volume	4939 c c.
Normal B.H P.	75
Maximum Hp.	80
Normal R P M.	1,800
Maximum R.P.M	2,000
Direction	Right-hand tractor.
Cylinder numbers	1, 2, 3, 4 from rear
Firing order	1, 3, 4, 2
Ignition	Dual, 2 B.T.H. type G.A. 4 magnetos
Sparking Plugs	2 per cylinder, K.L.G., F. 15 or Lodge A. 21
Oil pressure	5 to 15 lbs.
Tachometer drive	Half engine speed

Fuel consumption	0.6 pts. per hp. hr.		
Oil consumption	0.019 pts. per hp. hr.		
Weight, dry	280 lbs.		
Weight of piston	25.5 ozs.		
Weight of connecting rod	20 ozs.		
Compression ratio	4.9 to 1		
Mean effective pressure	110 lbs. per sq. inch.		
Diameter of inlet value	45 m/m.		
Diameter of exhaust valve	40 m/m.		
Lift of inlet valve	9 m/m.		
Lift of exhaust valve	9 m/m.		
		Inner	*Outer*
Strength of inlet spring, open		9.5 lbs.	23.5 lbs.
Strength of inlet spring, closed		15.5 lbs.	34.5 lbs.
Strength of exhaust spring, open		9.5 lbs.	23.5 lbs.
Strength of exhaust spring, closed		15.5 lbs.	34.5 lbs.
Length overall	1161 5 m/m.		
Height overall	904 m/m.		
Width overall	482 m/m.		
Bearer centers	540 m/m.		

General Description.—The A.D.C. "Cirrus" (Mark II) engine is of the vertical, four-cylinder-in-line, air-cooled stationary type. Bore and stroke are respectively 110 millimeters and 130 millimeters. At 1,800 revolutions per minute the engine gives an output of 75 brake horsepower, and at 2,000 revolutions (i.e., the maximum revolutions at which the engine should be run), the output is 80 brake horsepower. Cylinders and cylinder heads are separate, the cylinders being of cast iron and the cylinder heads of aluminum alloy, with air-cooling fins cast on each. The cylinders are spigoted into the crankcase and into the heads, the joints between the cylinders and heads being made by copper and asbestos washers. The complete cylinder with head is secured to the crankcase by means of four studs projecting from the crankcase and passing through holes in the cylinder head. In the cylinder heads special bronze seatings for the exhaust and inlet valves are screwed and expanded into position. The valve guides, which are a force fit in the heads, are of phosphor bronze. Provision is also made in each cylinder head for fitting two sparking plugs, two gun-metal screwed bushes being fitted.

Valves and Valve Gear.—In the crown of each cylinder-head one inlet and one exhaust valve is fitted. Both valves are operated by rocking levers, which are in turn operated by means of push rods in conjunction with the tappet rods located in the upper part of the crankcase. The tappets are actuated directly by the camshaft.

The rocking levers are carried on a separate steel bracket, which is bolted to the platform provided on top of the cylinder heads. The valves are of a special nickel steel known as K. E. 965, and the valve springs are of the spiral coil type, and are secured by means of split collets and collars. The timing of the valves when cold is as follows:—Inlet opens twelve degrees before top dead center. Inlet closes 70 degrees after bottom dead center. Exhaust opens 70 degrees before bottom dead center. Exhaust closes 28 degrees after top dead center.

The valve tappet clearances (cold) are as under:

Inlet	.005-inch
Exhaust	.020-inch

Pistons and Connecting Rods.—The pistons are aluminum alloy castings, the crowns of which are adequately reinforced on the underside by cross webs. They are fitted with three piston rings of cast-iron. The lowest of these rings also acts as a scraper ring, insomuch as a groove is turned in the piston immediately below it, and a number of small holes are drilled around this groove through which oil can escape into the inside of the piston. This arrangement prevents any excess of oil on the cylinder

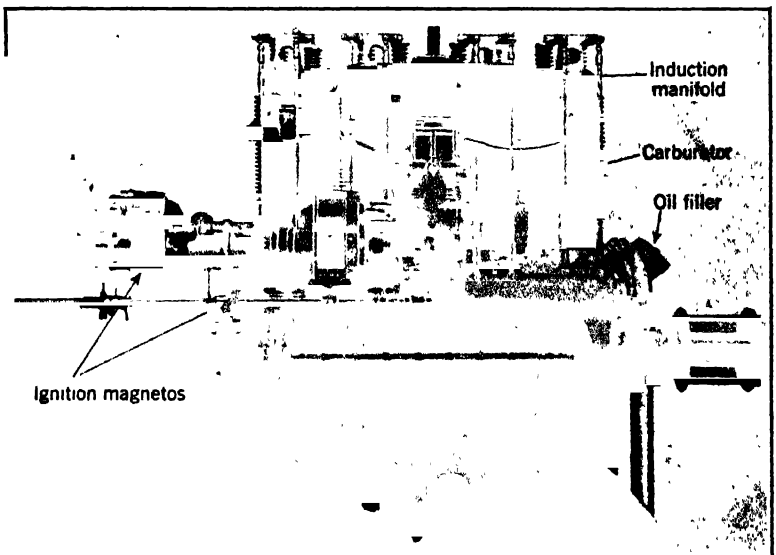


Fig. 497.—Carburetor Side of A.D.C Mark II Cirrus Engine.

walls from finding its way into the combustion-chamber. The hollow wristpin is of the full floating type, that is to say, it is free to turn both in the housings in the piston and also the small end of the connecting rod. End play, beyond the maximum tolerance, is prevented by a spring clip or circlip at each end, which is inserted into the housing and allowed to expand into an annular groove, into which it is only forced more tightly when pressed by the end of the wristpin. Holes are drilled in the gudgeon pin housings, and also in the small end of connecting rods, through which oil thrown up into the cylinder can enter, affording ample lubrication for the working surfaces.

The connecting rods one of which is shown at B, Fig. 500, are made from duralumin forgings of "H" section. The cap of the big end is registered to the rod by two bolts, and the big ends are fitted with die-cast white metal bearings. On the back of the cap-half of bearing a dowel is provided, cast

integral with the bearing, which registers into a recess in the cap and prevents rotation of bearing. As an alternative, phosphor bronze white metal lined big end bearings can be supplied.

Crankshaft.—The four-throw crankshaft is of solid construction, and, as can be seen from the illustration, Fig. 500 A, an extension forming the propeller shaft is secured to the forward end by means of a keyed cone hub and bolts. The complete shaft rotates in five bearings, viz., three die-cast white-metal center bearings, and a roller bearing at each end. The caps for the roller bearings and center bearings are carried by the upper half crankcase, and are secured by studs and nuts. The caps are steel and of robust design. In addition to the bearings mentioned above, a radial thrust bearing is fitted on the extension of propeller shaft.

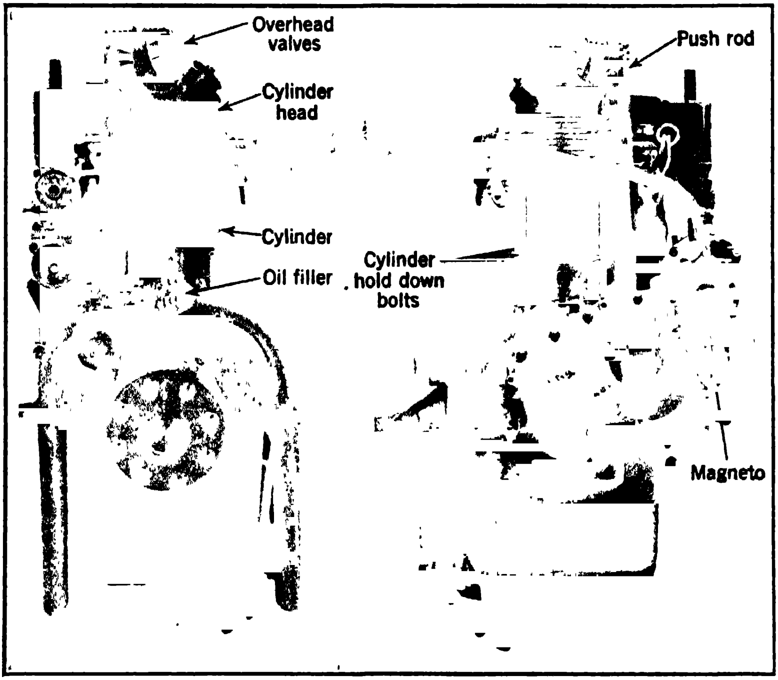


Fig. 498.—Propeller End of A.D.C Cirrus Engine Shown at Left and Anti-Propeller End Shown at Right.

Crankcase.—The crankcase is an aluminum alloy casting, divided along the center line of the crankshaft. The upper portion is stiffened by three transverse webs, which also form the housings for the center bearings. Housings are also provided in the upper portion for carrying the camshaft bearings and the upper oil pump spindle bearings. Provision is also made for securing four bearer or supporting feet. Housings for the ball bearings carrying the timing gears are provided in the upper half and timing gear cover. On the front wall above the nose a small casting is secured,

which acts as an oil filler, and to which breather pipes are attached. The lower half, beyond forming in itself a cap for the radial thrust bearing, merely acts as an oil sump and a cover for the moving parts. The upper and lower portions are bolted together, the joint being effected by means of a brown paper washer.

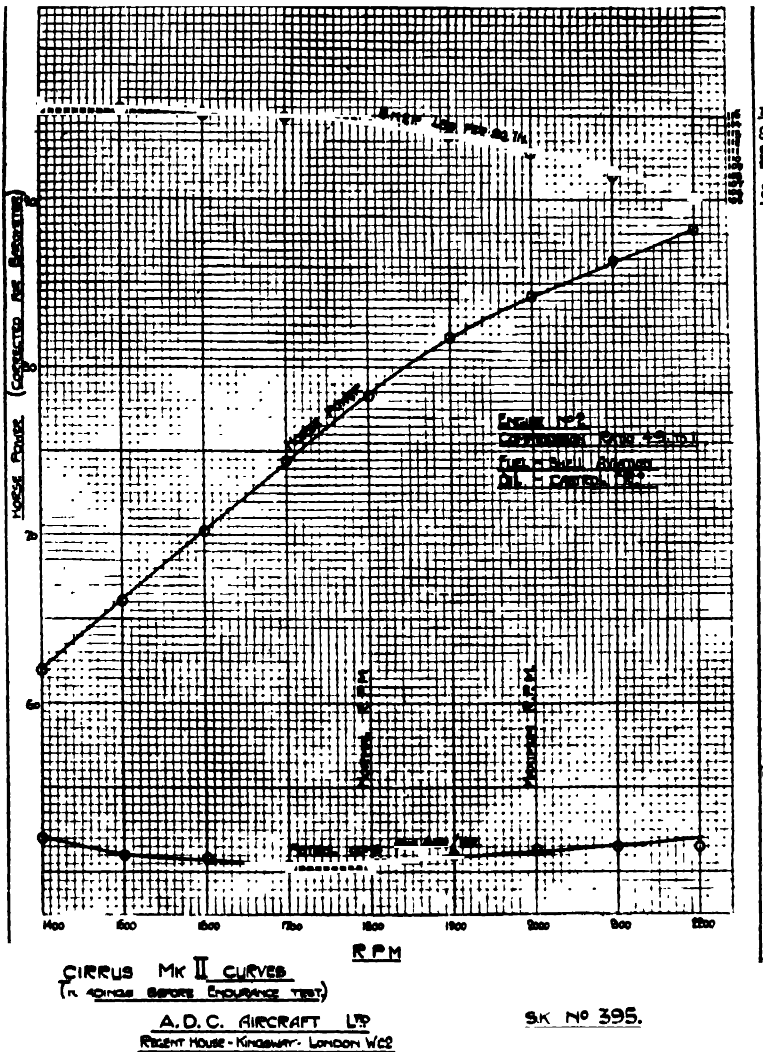


Fig. 499.—Power and Consumption Curves of the A.D.C Cirrus Mark II Aviation Engine.

Camshaft.—All the valves are operated by a single camshaft. It is supported in four bearings, the rear being a large ball bearing and the remainder phosphor bronze. The shaft is driven off the end of the crankshaft through the medium of steel gears supported, as already mentioned, between ball bearings housed in the top portion of crankcase and timing gear cover. The camshaft is clearly shown at Fig. 500 C. A spiral gear integral with the camshaft and situated centrally drives the oil pump spindle. Provision is made to couple the tachometer drive to the rear end of the camshaft. The timing gear assembly is shown at Fig. 500 D.

Induction Manifold.—The induction manifold is of steel, with branches to each inlet valve port as shown at Fig. 497. A heated muff is provided in the central section, a pipe being taken from the exhaust manifold so that the exhaust gases can circulate therein. The joints between the induction manifold, cylinder heads, and carburetor, are made with "Hallite" washers.

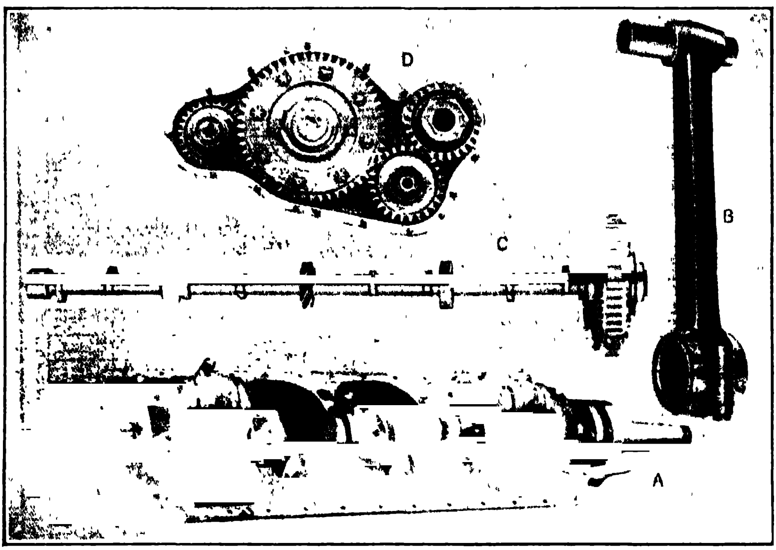


Fig. 500.—Typical Parts of the Cirrus Mark II Engine Showing Substantial Construction. A—Part of Crankcase with Crankshaft in Place. B—Connecting Rod. C—Camshaft and Timing Gears. D—Timing Gear Assembly.

Lubrication.—The lower half of the crankcase (usually termed the oil base) will contain twelve pints of oil, which is sufficient for above five hours' flight. The oil pump is arranged at the lowest part of the base, so that it is always flooded or self-primed with oil. The oil pump, which is a gear type, forces the oil through a gauze filter, which is arranged horizontally just above the pump, thence through the main delivery pipe to the oil gallery arranged on the port side of the engine. The oil gallery is connected to passages cast in the top half of the crankcase, which run to the center and intermediate bearings; the oil is thus forced under pressure direct to each bearing. A diagram of the oiling system is given at Fig. 501.

The crankpins are lubricated as follows:—An oil thrower or banjo is fastened to the crankwebs, and the oil overflowing from the adjacent main bearing is caught into the interior of this thrower and forced out by centrifugal action to the crankpin; the excess of oil thrown off the crankpins lubricates the other parts of the engine, some portion of it going into the cylinders to lubricate the pistons and gudgeon pins. The camshaft, being open to the interior of the crankcase, gets sufficient oil thrown on to it to lubricate its bearings, and also the valve tappets and guides. Quarter-inch pipes are connected to the ends of the oil gallery, the forward pipe carrying oil to the propeller shaft radial thrust race, and the rear pipe to the timing gears, so that the oil from it lubricates the teeth of the gears.

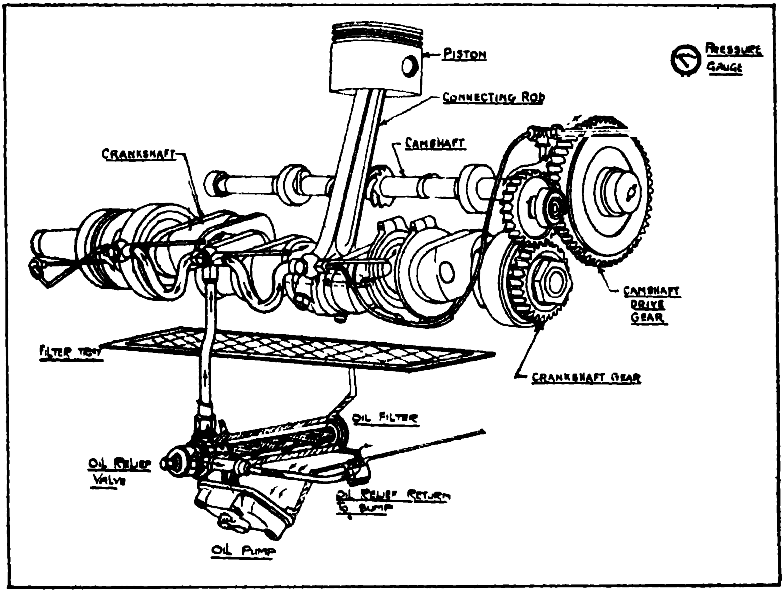


Fig. 501.—Oiling System of the A.D.C Mark II Cirrus Engine.

A few moving parts on the outside of the engine, such as the rocking levers, pins and tappet guides, must be oiled or greased daily. A "Tecalemit" grease gun is provided for forcing grease to the rocking levers and pins. Valve stems should be kept clean and well lubricated. A gauze strainer is fitted in the upper part of the base, as shown at Fig. 501, through which all the oil passes after doing its work in the engine; it then drops to the bottom of the base and is used again. The oil should be drained out of the crankcase after about every nine hours' running, the strainer gauze carefully cleaned and fresh oil put in. The pump strainer should be cleaned after six hours' running. A level indicator, which is graduated in quarts, is placed down the side of the base so that it can easily be withdrawn and the level of oil ascertained.

Oil Pressure.—Provision is made for connecting the oil pressure gauge through the three-way piece fitted in the timing gear cover. Pressure

should be maintained at about five to fifteen pounds when the engine is hot. A relief valve is fitted, but should only come into operation when starting up cold, as the oil pressure will then mount up to 25 to 30 pounds, due to the oil being very much thicker, and requiring much more effort to force it through the various passages. Sufficient time should be allowed for the oil to warm up before regarding the pressure on the gauge as the normal pressure when flying. As a general rule, when the engine is running warm, all the oil being pumped should pass to the bearings, and no additional pressure should be recorded on the gauge if the relief valve is held in for the purpose of trying this.

If, however, the engine is using above the average quantity of oil, the spring on the relief valve should be adjusted to slightly less pressure, when a portion of the oil would be returned to the base instead of all being forced to the bearings. The average consumption of oil should be about .019 pints per horsepower hour. Efficient lubrication with a good quality oil is a most important feature. The following oils are recommended:—Castrol "R." Vacuum "B.B." Shell "Super Heavy A." The illustrations of the port and starboard sides of the engine show clearly several of the points which have been described.

Ignition.—Two sparking plugs are fitted in each cylinder, and they are placed at opposite sides of the combustion head in order to promote the maximum rapidity of inflammation of the mixture. They are fired by two four-cylinder high-tension magnetos, which are mounted in tandem. The magnetos are manufactured by Messrs. The British Thomson-Houston Co. The forward magneto is carried on a bracket or platform cast integral with the upper half crankcase, while the rear magneto is overhung or spigot mounted to the timing gear cover. They are driven by a common shaft, running parallel to the camshaft, and this shaft is driven by the camshaft. The forward magneto is of the "G A. four platform type," runs in an anti-clockwise direction, and is coupled to the driving shaft by means of a flexible coupling provided with a vernier adjustment to facilitate timing. The magneto is also fitted with an automatic impulse mechanism which operates in such a manner that when the magneto is turning over slowly, i.e., when turning the propeller, a spring is put into tension and then suddenly released, causing the magneto to revolve rapidly, thus creating a fat spark at the plugs. The rear magneto, known as the "G.A. four spigot-mounted type," runs in a clockwise direction. This is coupled to the driving shaft by means of a finely serrated coupling. The normal timing of the magneto is such as to provide a maximum advance of 35 before the top dead center. The order of firing is 1, 3, 4, 2, and the cylinders are numbered from the rear end.

If the engine will not start, and the ignition is suspected to be the cause, first see that the magnetos are sparking. To do this, remove a high-tension wire from the plug terminal, place it close to the cylinder, when on engine being turned round by hand, the spark should be visible. Should no sparking occur, examine the magneto as follows:—Remove distributor and clean the inside of it with a cloth soaked in gasoline. The surface of the brush holder, particularly between the safety gap electrodes, should be cleaned in a similar manner. Remove the dust cover and take out the collector brush

holder. The cone of the latter should be wiped free of all dust with a cloth soaked in gasoline. Do not remove brush from collector moulding unless necessary. The flanges of the slip ring should be cleaned by lightly pressing one corner of the cloth between the flanges and slowly turning the engine crankshaft. The contacts should be clean and free from oil. If contacts are dirty, remove the contact breaker bodily from the armature spindle, after first removing the center fixing screw. Clean the contacts with very fine emery cloth or paper, afterwards removing all trace of emery. Re-fit contact breaker, taking care to locate the key on the contact breaker base in the keyway of the armature spindle. Check gap of the contact breaker with the feeler gauge, and adjust with the spanner, if necessary. When the heel of the contact lever is on the high part of the cam, the gap should be 0.012 inch.

Lubrication of Magneto.—The only part needing lubrication is the distributor gear-wheel bearing. Only a few drops of light oil, put in the oil well at the distributor end of the magnetos, are required. The magneto should never be completely dismantled, as all parts that need attention are so arranged as to be easily accessible. The dismantling, therefore, will not serve any useful purpose, and only those who are perfectly familiar with such apparatus will succeed in re-assembling it properly.

Misfiring in one or more cylinders can nearly always be put down to faulty plugs; they should be frequently examined, and cleaned with a little petrol. The plugs used on this engine are Lodge A 21 or K.L.G. F. 15; the distance of the gap at the plug points should be .015 inch. If the gap is too large, the spark will jump across the safety gap instead of the points in the plugs, so that the mixture in the cylinders will not be ignited. A plug may fail owing to the insulation having broken down; if this is found to be the case, the plug must be replaced by another.

Carburetor.—The type of carburetor fitted is the "Claudel Hobson" (R.R.C.H.) A cross sectional elevation of this carburetor is illustrated at Fig. 502. From this it will be seen that the diffuser consists of three concentric tubes, the one "J" called the depression tube, being screwed into a plug "O" and drilled with a number of small holes "I." The plug "O" is screwed into the carburetor body and carries at its lower end another plug "P" which has a number of holes drilled around it to allow petrol to enter the diffuser. Surrounding the tube "J" and soldered to the plug "O" is a second or guard tube "H." The upper end of this tube "H" comes within a short distance of the "emulsion head" "D," the interior communicating with the atmosphere through the medium of the holes "N" at the base of the outer tube "G." A slow running jet, "L," is screwed into the plug "P," and passes through the depression tube "J," projecting into the throttle barrel "B." In the latter, a slot "A" is cut, which, when the throttle is closed, or partially closed, forms a suitable choke around the slow running jet. A screw "C" known as the "air screw" projects to a greater or lesser degree into the slot "A," for providing a means of adjusting the mixture for slow running, or small throttle opening.

The fuel level is normally adjusted to stand below the top of guard tube "H." As the air velocity through the choke increases, this level tends to fall, uncovering some of the holes "I" in the depression tube "J." Air

is then drawn in through the holes "N" entering such holes in the depression tube as may be uncovered. Within the depression tube, this air mixes intimately with the fuel forming an "emulsion" which is finally expelled through the holes "E" in the emulsion head "D." Further increase in air velocity through the choke lowers the fuel level within the guard tube "H" still more, uncovering thereby other holes in the depression tube, and admitting more air. By this means the ratio of fuel to air is kept approximately constant for varying engine speeds.

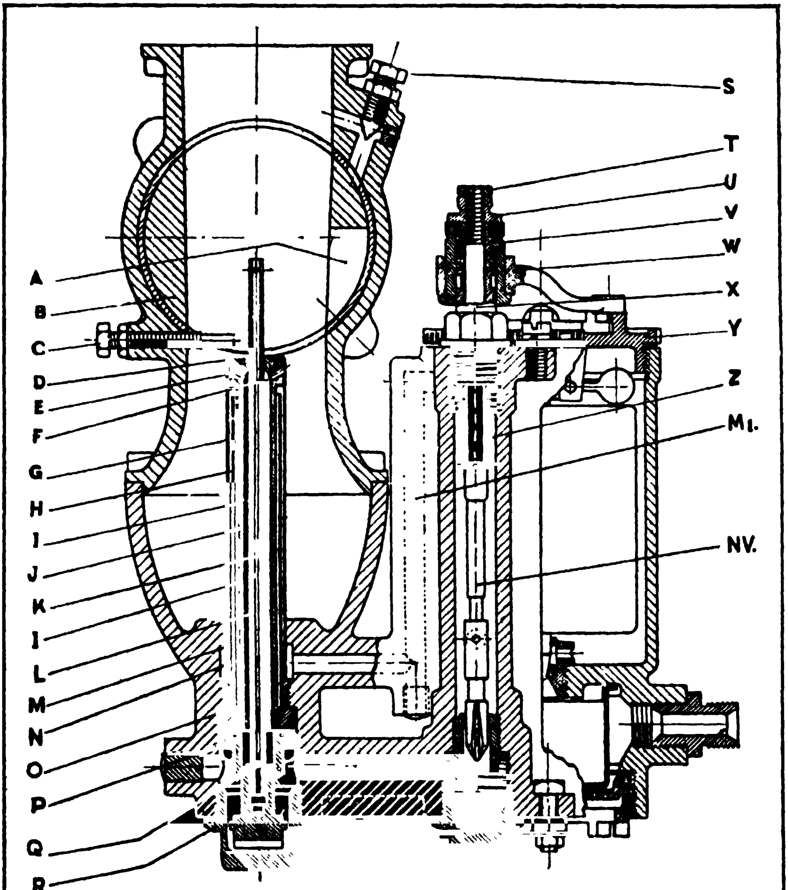


Fig. 502.—Part Sectional View Showing Construction of Claudel-Hobson Carburetor Used on Cirrus Mark II Engine.

When the diffuser is removed for inspection, care must be taken in handling the parts, as they are made of very thin material and are easily crushed or bruised. When re-assembling, see that the outer tube "G" is correctly seated upon the spigots provided before screwing up the depression tube "J." This outer tube must be replaced with the holes at the

bottom of the diffuser. Reference to the drawing will show that the plug "P" screws up against the end of depression tube "J." In order to ensure that the outer tube "G" is held securely in position, the depression tube should be screwed up before the plug "P." When the throttle is in the closed position, that is, set against the stop provided, sufficient petrol is supplied by the pilot jet "L" to run the engine slowly. Fuel enters this jet through holes "Q" at the base, a restriction "K" regulating the amount which may pass. Above this, restriction holes "F" are arranged, their function being the admission of air to form a finely atomised mixture. The duty of the air-screw "C" is to provide a means of adjusting the choke area around the pilot jet, that is, the area of the slot "A," thereby enriching or weakening the mixture supplied at closed throttle or small openings. It should be noted, however, that its effect upon the mixture rapidly decreases as the throttle is moved from the slow running position, and at full or moderate throttle openings ceases altogether. A bypass is provided past the throttle, controlled by the screw "S." This regulates the quantity of gas passing to the engine when running slowly, the quality being controlled by the air screws.

A means of correcting the mixture is provided on this carburetor by means of a variable jet. This is arranged, as shown, in the passage from the float chamber, and consists of a needle valve provided with tapered slots or grooves, so disposed that the area of the passage is varied, according to the vertical position of the needle. The operating mechanism for this needle valve has been so arranged that it is a comparatively simple matter to alter the setting of the valve. The needle valve is shown at "NV," its spindle passing through the plug "X," which is screwed into the body of the carburetor. This plug "X" is provided on the outside with a coarse-pitch square thread, and on to this thread is screwed a sleeve "V," to which is clipped the control lever "W." A collar "U" screwed on to the needle valve abuts against the sleeve "V," "T" being merely a lock-nut. On moving the lever to rotate the sleeve, it will be observed that the valve is lifted, its return motion being controlled by the spring "Z."

The best position for the screwed collar "U," relative to the tapered grooves of valve "NV," is found when the engine is under test, the top of the spindle being then filled flush with the lock-nut and carefully marked. This setting should on no account be altered and should it have been necessary to release the lock-nut "T" for dismantling purposes, care should be taken to replace and lock it in position according to the marks referred to. Special provision has been made on this carburetor to neutralize the effects of localized pressure variations due to eddy currents. On the drawing it will be observed that a passage "M" is provided, connecting the top of the float chamber with the main air intake. In addition, air supplied to the diffuser is taken from the same source, namely, through the holes "N." The result is that the mixture strength is maintained constant despite slight variations of pressure due to eddy currents in the vicinity of the inlets.

Dismantling Engine.—Assuming that the engine is out of the airplane and it is necessary to dismantle it, the following procedure should be adopted and the parts taken off in the order indicated:—Small parts should be placed in boxes, and nuts replaced on their respective bolts as each is

dismantled. Place engine on convenient stand or trestles. See that oil is drained out of base. Remove exhaust manifold. Remove plugs. Remove push rods. Remove control shaft. Remove inlet manifold and carburetor. Remove magnetos. Remove tappets, oil pump drive, oil filter and breather pipes. Remove the nuts securing cylinder, and then remove the cylinder heads.

If the head is tight on the cylinder, it is better to remove the whole cylinder assembly, afterwards removing the head by a few blows with a piece of hard wood inside the cylinder. On no account attempt to pry the head off by means of a lever under the fins. The pistons can now be removed by first extracting the circlips which position the wristpin laterally. Before placing the pistons on the bench, note should be taken of the cylinders to which they belong, and the wristpins placed in their own pistons.

Remove the nuts securing timing gear cover, and then ease off the cover by gently tapping the lugs provided for this purpose. Remove the timing gears, but first see that they are marked as shown on photograph of the timing gear with punch marks to show proper points for meshing the teeth. Next remove the four screws from the oil retainer and timing disc on the front of the engine. Do not pry it off, it can be removed with shaft when sump is off. The oil gallery can now be removed. To remove camshaft, first remove end plug and drive out shaft with a brass drift. The engine can now be turned over and the sump removed. The crankshaft assembly is now exposed as at Fig. 500 A. First remove oil throwers from crank webs and then the main bearing caps. The whole crankshaft with connecting rods can then be taken out. On no account should the propeller shaft be dismantled except when it is necessary to be renewed. Dismantle the connecting rods from crankshaft. Remove the oil pump at base of sump. Remove the oil relief valve and oil filter from base of sump.

Assuming that the engine has been taken down for overhaul, the following is the procedure of re-examination and re-assembly, first taking care that every part has been thoroughly washed in kerosene and left to dry by draining, not by wiping, as this is liable to leave particles of material which will stop up oilways, filters, etc. All oil passages should be powerfully syringed through. Examine big ends of connecting rods for slackness and soundness of white metal. Do not fit too tightly. The rod should be so fitted that it is quite free without any feeling of rock. Examine gudgeon pin for wear and slackness in piston and small end of connecting rod.

Examine the crankshaft, also the ball and roller bearings for wear and the gear for wear and fit. When re-fitting to crankcase, remember that the crankshaft is located by the three ball bearings; if when these are clamped into position the shaft is more than .002-inch off either the center or intermediate white-metal bearings, the bearing should be replaced. Do not fit the bearing caps so that the shaft is forced to meet the upper halves. When fitted, it should be possible to turn the whole assembly by hand without effort. When the crankshaft assembly is in position, the oil throwers or banjos should be fitted and carefully locked with wire. Examine the camshaft for condition of cams and gears, also examine the camshaft bearings in crankcase for wear.

The oil pump, bottom filter and oil release valve, after examination, should now be fitted to the sump. See also that the large oil strainer gauze is cleaned and fitted. The sump can now be fitted to the crankcase. The engine can be turned over. The pistons should be cleaned of carbon deposit, inside as well as out. Carefully examine rings. If worn or distorted, or if there is any sign of "blowing past," change for new. These should be then well lapped into the cylinder. The piston rings being of cast-iron and small in section, are very delicate and easily broken. They can best be removed from the piston by using three strips of tin or ground down hacksaw blades about ¼-inch wide, which are placed at equal distances round the piston and under the ring to be removed, which can then be slipped off easily. It is necessary to thoroughly clean the grooves into which they fit, as, if any deposit is left in the grooves it forces the rings out and makes them too tight a fit in the cylinders. Check the ring gaps and also the side clearance in the grooves. Check clearances of gudgeon pin and piston. After this examination pistons can be fitted, care being taken to ensure that the circlips have been fitted to position the gudgeon pin.

Clean cylinders and heads. Examine valves and valve seats, and check valve guide clearances. If found necessary to fit a new valve, this should be ground in with grinding paste, or floured emery mixed with oil. A valve should not be ground by continuous rotary motion, but by turning it backwards and forwards on its seat, two revolutions at a time, and lifting it off its seat at each reversal of motion. A bright ring should be obtained on the valve and seat. It is essential to see that both are good, as it is possible to obtain a bright ring on the valve when it is only resting on three points. After this operation, valves and seats should be thoroughly cleaned by washing in kerosene oil and left to drain. See that no sharp points are left anywhere in the heads, as they may cause preignition; for example, the screwdriver or tool used in valve grinding may have burred up the slot. Cylinders and heads should now be fitted. The head should be placed evenly on the cylinder, with preferably a new copper and asbestos washer between.

Examination and Assembly of Engine.—The cylinder holding down nuts should then be tightened, giving half a turn to each, working from opposite corners until the head is held firmly in position, and the joint just air-tight. If there is a leakage past the joint when running, the washer will soon get burnt away. On the other hand the head must not be screwed down too tightly or when expansion takes place it will be liable to crack. The faces of the inlet and exhaust ports should be checked with a straight-edge for alignment, otherwise air leaks and/or strained manifolds will result. The induction manifold should now be fitted, care being taken to ensure that the "Hallite" washers are fitted at joints. Tappets, push rods and rockers should now be assembled. Now secure the oil retainer and timing disc to nose, and the engine is ready for valve timing.

Instructions for Valve Timing.—All engines are erected with timing marks on gears as shown on the illustration of timing gears. To time the engine, it is only necessary to engage the idler or intermediate gear so that these marks correspond.

If it should be necessary at any time to replace any part of the gearing,

thereby having no marking to guide in the erection, proceed as follows:

Set the tappets of No. 1 cylinder to the correct clearance, then with the idler gear out, turn the crankshaft until the pointer on the propeller boss shows inlet valve opening, then turn camshaft in a clockwise direction until No. 1 inlet valve is just about to open and mesh in idler gear. If the gear will not mesh, the camshaft gear must be turned on its hub or boss one hole. Again set the camshaft as before mentioned, when the idler will be able to be inserted into position. Having set the pointer correctly, the gears should now be marked. The valve timing diagram is shown at Fig. 503.

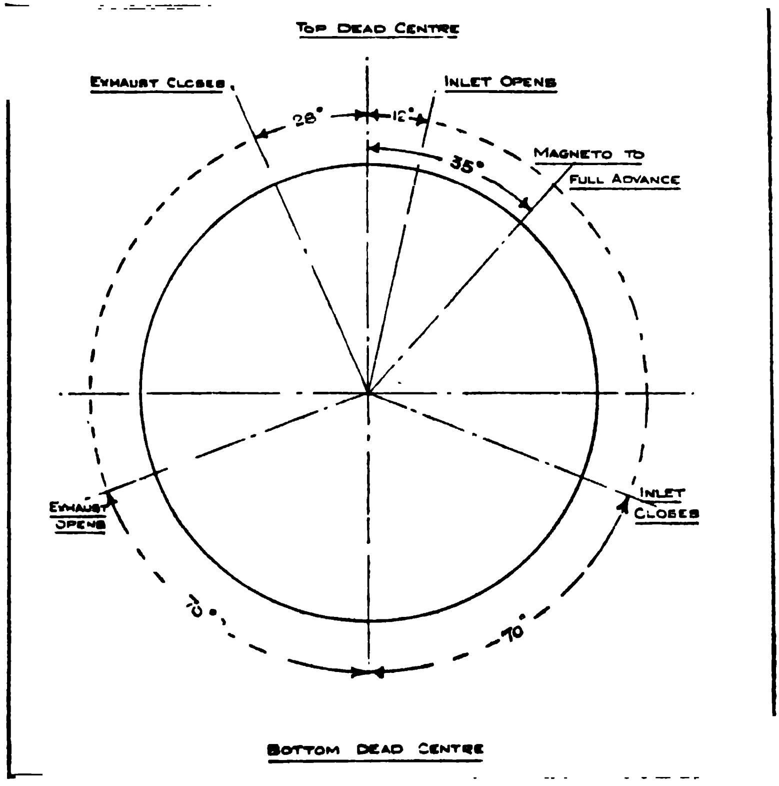


Fig. 503.—Cirrus Valve Timing Diagram.

When the engine has been timed correctly, replace the timing gear cover, but make sure that the joint washer is fitted between crankcase and cover. Replace magneto drive housings and drive. Time magnetos, and adjust all clearances. To time rear magneto: Set No. 1 cylinder so that the pointer on the propeller boss indicates magneto advance, i.e., 35 degrees. Set magneto so that the points are just breaking, with the rotor at the position of No. 1 on the distributor, making sure that the breaker cover is at the full advance position. The serrated coupling can now be placed in mesh;

secure magneto to cover and lock the screws with wire. To time front magneto: Set rear magneto so that the points are just breaking. Now set front magneto likewise and engage the vernier coupling. Care should be taken not to engage this coupling too tightly in mesh, otherwise early failure of the impulse starter mechanism will occur.

The oil pump drive can now be replaced. Fit carburetor and support bracket. Fit oil gallery pipe. It is advisable to replace old washers with new ones, treating these with a little shellac or hermetite. Fit breather pipes and oil filler.

Running Instructions.—See that the ground wire is in position and that the switch is off. Turn on gasoline and then give the propeller two or three swings to suck a charge in. Now get the propeller in such a position that the engine is just on compression, and the impulse starter about to act. Then, with switch on and the throttle slightly open, give a sharp pull over, when the engine will start up. When the engine has started it should be run at a moderate speed, say 500 to 600 revolutions, for about five minutes, after which the throttle may gradually be opened up to full throttle. On no account should the engine be rapidly accelerated from cold, as time must be allowed for the oil to get warm and so flow easily through the lubrication system, otherwise a sufficient supply may not be fed to the bearings, etc., and serious damage may ensue. The oil pressure should be between five to fifteen pounds when warmed up.

Should repeated efforts fail to start the engine, or the running be faulty, the following are likely reasons:—1. The impulse starter may be sticking, due to gumming oil or dirt. Wash out with kerosene and lubricate with thin oil. 2. Faulty carburetion. See if the fuel is reaching the carburetor properly. If it is not, it may be due to any of the following causes: No fuel in tank. Fuel not turned on. The air vent in the filler cap of tank or the vent pipe may be stopped up. A drop of water may get into the supply pipe and cause trouble, or an air-lock may stop the supply. The needle valve in the float chamber may stick. The wire gauze of the filter may be dirty; this should be cleaned out at frequent intervals. Some obstruction in the piping may require removing.

The mixture may be weak, due to choked jet. A weak mixture will cause backfiring or popping in the carburetor. It is rarely through any defect of the inlet valve that popping occurs, but it is possible for particles of grit to get under the seat, and prevent it closing properly, or for a valve to stick in its guide. An important point to remember is that when a machine ascends, the air becomes rarefied, and an engine which is giving its full power on the ground may drop in power considerably when in flight, although the propeller speed usually increases. The maximum revolutions per minute on the ground are usually about 1,750 to 1,850. This fact, that the engine has to run in a different atmosphere when in flight, has to be taken into account when testing on the ground and must modify to some extent the conclusions that are come to in the latter case.

The mixture may be too strong, due to flooding. This is caused by the needle valve in the carburetor not seating properly, either by some particle of dirt getting under the cone, or the valve may require grinding in. The latter should be done very carefully, without using emery or grinding paste,

as anything gritty will destroy the surface; a little metal polish will probably enable the valve to be ground quite tight upon its seating. A punctured float will also cause flooding. This can easily be cured by immersing the float in hot water, when the fuel in the interior will evaporate and enable the leak to be located; the leak can then be soldered up. When engines leave the works the variable jets are locked in position after the engine has been tuned up on the standard airscrew.

Missing Fire, May be Due to.—(a) Faulty plug. If possible, discover the cylinder at fault and fit new plugs. In case of doubt, change all plugs. (b) Contact breakers on magnetos sticking. (c) Faulty ignition leads. (d) A sticking valve or broken valve spring. (e) Incorrect adjustment of tappets.

Overheating.—The cause may nearly always be put down to a weak mixture, due to a choked jet, too small a jet, or air-leaks between the carburetor and inlet valves. In the case of one of the cylinders only giving trouble, it will usually be found that the compression is weak, and on fitting a new cylinder head joint and induction pipe joints and a new set of piston rings, well lapped into the cylinder, the trouble will disappear. (It is most important that the compression in all the heads should be constant.) Overheating may also be caused by preignition due to dirty condition of combustion heads or faulty plugs. Running the engine with open exhaust will soon show up which of the cylinders are running well and which are not. The exhaust should have a blue Bunsen-like flame, and a white or yellowish flame indicates a weak mixture, which will eventually heat the cylinder and cause trouble, while red flames or black sooty exhaust indicate a rich mixture.

Poor Compression in Cirrus Engines May be Due to.—(a) Faulty valves or valve seats which require regrinding. (b) Incorrect tappet clearance, preventing the valves seating properly. (c) Broken valve spring. (d) Valve not free in guide. (e) Valve rocker binding on pin. (f) Faulty sparking plug or adaptor. (g) Broken piston ring.

Unsuitable Propeller.—Failure to attain the correct rate of revolution may be due to an unsuitable propeller and not to any fault of the engine. Should the maximum speed of the engine, therefore, be below the normal, although none of the foregoing faults are present, another propeller known to be correct should be tried. An engine vibrating or knocking excessively should be stopped as soon as possible. A regular vibration is probably caused by an unbalanced propeller, and another should be tried. Vibrations occurring only at certain speeds may be caused by loose holding-down bolts or slack fittings on the engine mounting. A propeller loose on its shaft, missing fire, preignition, or excessive tappet clearance are all likely to cause knocking, as are loose bearings and overheating.

Maintenance.—After each day's flying. (1) Clean out fuel filters. (2) Inspect carefully all engine controls. (3) Examine fuel and oil pipe line joints. (4) Check the tightness of all main nuts and bolts. (5) Inspect valve gear and cylinder heads. Check valve clearances. (6) Test propeller hub for tightness on crankshaft and propeller for tightness on hub. (7) Clean out oil pump strainer.

After each ten hours: (1) Charge the rocker fulcrum pins with grease, using the Tecalemit grease guns supplied. (2) Grease push rods and valve stems with graphite grease. (3) Clean sparking plugs and re-set gap. (4) Drain and flush out carburetor float chamber. (5) Check tappets. Inlet .005-inch, exhaust .020-inch. (6) Change oil, drain while engine is hot.

After twenty hours, in addition to the points called for after ten hours. (1) Examine contact breaker. (2) Examine and clean magneto distributor.

After each 100 hours running. A top overhaul should be given, the cylinder heads being lifted and de-carbonized, and the valves dismantled, examined and reground in, if necessary. The cylinders can be lifted during this operation and the condition of the pistons, gudgeon pins, etc., ascertained. After 300 hours running the engine should be removed from the machine, completely stripped, cleaned, inspected and overhauled.

Table of Clearances.—To facilitate examination for wear the following table of clearances allowed on the working parts, when new, is given for reference:

Main bearings, diameter clearance between bearing and shaft:		
	Min. .0015 in.	Max. .004 in.
Side clearance center bearing each side:		
Front	Min. .010 in.	Max. .015 in.
Rear	Min .030 in.	Max. .040 in.
Connecting rods, diameter clearance between bearing and shaft:		
	Min. .0015 in.	Max .004 in.
Side clearance	Min. .010 in.	Max. .020 in. (total)
Gudgeon in piston:		
	Min. .0005 in.	
	Push fit	Max. .0015 in.
Piston in cylinder:		
	Top.	Bottom.
	Min. .026 in.	Min. .020 in.
	Max. .035 in.	Max .024 in.
Ring gap:		
	Min. .020 in.	Max. .030 in.
Clearance in grooves:		
	Min. .005 in.	Max. .007 in.
Camshaft bearings:		
End	Min. .001 in.	Max .004 in.
Intermediate	Min. .0015 in.	Max .005 in.
Oil Pump drive bush:		
	Min. .001 in.	Max. .0035 in.
Valve guides:		
Exhaust	Min. .004 in.	Max. .006 in.
Inlet	Min. .003 in.	Max. .005 in.

Valve tappet clearances:

Inlet	.005 in.
Exhaust	.020 in.

QUESTIONS FOR REVIEW

1. Outline main features of A.D.C. Cirrus engine.
2. Describe Cirrus cylinder construction.
3. What are valve tappet clearances used with A.D.C. Cirrus engines?
4. Describe Cirrus engine crankshaft construction.
5. Outline Cirrus engine lubrication system.
6. What oil pressure should be used on Cirrus engines?
7. Describe construction of carburetor used with Cirrus engines.
8. What precautions are necessary in removing cylinder heads from cylinders?
9. How is valve timing done on Cirrus engines?
10. Outline main running instructions for Cirrus engines.
11. What is the piston clearance in Cirrus engines?
12. What is the correct piston ring gap?
13. What clearance is allowed in valve stem guides?
14. Do connecting rod big end bearings have running clearance? If so, what is it?
15. What is the side clearance each side of crankshaft center bearing and why is it necessary

CHAPTER XXXI

RYAN-SIEMENS ENGINE

Main Features, Ryan-Siemens Engines—Specifications, Ryan-Siemens Engines—Fitting Engine in Fuselage—Exhaust Collector and Pre-heating Device—General Description—Fuel and Lubrication Systems—Ryan-Siemens Ignition—Starting the Engine—Running the Engine—Dismantling the Engine—Assembling the Engine—Special Tools for Ryan-Siemens Engines—Ignition Troubles—Carburetion Troubles—Lubrication Troubles—Miscellaneous Troubles—Top Overhaul—The Sum Carburetor.

The Siemens Radial Engines are air-cooled engines with five, seven, or nine stationary, nonrotating cylinders arranged radially and in one plane on a crankcase split on the center line, which contains the single-throw crankshaft with ball bearings. The drop valves are operated by thrust rods and roller tappets. The cam drum is driven by a toothed gearing in the front crankcase. Four, six, and eight connecting rods are connected in a joint to the head of the master rod operating upon the crank over two sturdy ball-bearings. The five-cylinder engine is provided with one carburetor, the seven- and nine-cylinder engines with two each. Each engine is supplied with two Siemens high-tension magnetos. These engines are known as the Siemens-Halske in Germany.

Main Features, Ryan-Siemens Engines.—On request the engines are equipped as follows: (a) Exhaust collector and preheater. (b) Electric starting device consisting of Bosch starter (type BGeo 6/12) and spur wheel rim fixed to the screw boss. (c) A special drive for the connection of a flexible shaft for operating a lighting dynamo, etc. Generally, the engines seen from the front as at Fig. 504, run clockwise; on request, though, they can also be supplied to run in the reverse direction. The engines are suitable for either a push- or pull-screw drive. All engines have a bore and stroke of 100 by 120 millimeters respectively, and a compression ratio of 1:5.6. The nominal outputs are 60, 84, and 108 horsepower respectively at 1,500 r.p.m. The engines reach a maximum output of 70, 96, and 125 horsepower at 1,750 r.p.m. The fuel consumption during an 80-hour continuous run under official supervision proved to be 230 gallons per horsepower-hour under full load; it is between 220 and 240 gallons per horsepower-hour. The oil consumption varies between eight and twelve gallons per horsepower-hour. The engines, with all auxiliary apparatus included, weigh 117, 148, and 173 kilograms respectively, in accordance with a unit weight of 1°67, 1°54, and 1°38 kilograms per horsepower. The weight of the screw boss of the five- and seven-cylinder engines is 3°1 kilograms and that of the nine-cylinder type 3°5 kilograms. The unit weight of these engines compared with the water-cooled vertical type is considerably lower. The construction is substantial and reliable; ball-bearings throughout, and two magnetos are employed. The Siemens engines are said to be particularly durable. They are greatly adapted to the high requirements in instruction

flights as well as in cross-country flights. The makers have provided amply equipped tool boxes containing all special tools required as well as a certain number of spare parts. All spare parts should only be obtained from the makers or their authorized sales agents. No guarantee can be given for spare parts purchased elsewhere.

SPECIFICATIONS—RYAN-SIEMENS ENGINES

		Model 5	*Model 7*	*Model 9*
Number of cylinders		5	7	9
Bore	Inches	3.937	3.937	3.937
Stroke	Inches	4.724	4.724	4.724
Piston displacement	Cubic inches	287.40	402.12	517.45
Compression ratio		5.6:1	5.6:1	5.6:1
Revolutions per minute		1500-1750	1500-1750	1500-1750
Guaranteed horsepower at sea level, 1750 R. P. M.	Horsepower	70	96	125
Normal torque	Pounds feet	217	289	361
Weight dry (without propeller hub)	Pounds	258	326	382
Weight of propeller hub complete	Pounds	6.85	6.85	7.72
Unit weight	Pounds per horsepower	3.68	3.40	3.05
Fuel consumption cruising speed	Gallons per hour	5-6	7-8	8-9
Oil consumption cruising speed	Gallons per hour	.14	.19	.23
Fuel consumption cruising speed	Pounds per horsepower hour	.49-.53	.49-.53	.49-.53
Oil consumption cruising speed	Pounds per horsepower hour	.018-.027	.018-.027	.018-.027
Maximum diameter	Inches	40.5	40.5	40.5
Maximum length	Inches	33.8	32.0	32.0
Dimensions of shipping crate	Inches	46x46x42	46x46x42	46x46x42
Approximate shipping weight	Pounds	630	675	720
Average additional weight of electric starter, including battery	Pounds	75	75	75
Average additional weight of exhaust collector ring with preheater	Pounds	12.5	15.5	20.0
Distance from front end of propeller hub to center of gravity	Inches	20.0	19.9	19.6
Distance from front end of propeller hub to mounting flange	Inches	24.25	24.25	24.25

Fitting Engine in Fuselage.—The chief point to be borne in mind when fitting the engine is the easy accessibility of the engine and all auxiliary apparatus and cables. It should always be easy to dismantle the magnetos as well as the oil- and air-pump (free space of about 30 centimeters at the back). The arrangement should be such as to permit of swinging out the engine with its framework from the plane (see Fig. 506). Hand oil- and air-pumps should be fitted so as to be easily accessible from the pilot's seat. The revolution meter should always be visible. In order to prevent fire, a fire-proof exhaust pipe should be used (Siemens exhaust collector) and provision be made for an outlet and sufficient ventilation for all chambers in which fuel is apt to gather in the case of leaks. In any case a fire bulkhead must be provided between the engine and the pilot's seat. The best position for the air supply tubes to the carburetors is outside the plane body well away from the exhaust tubes. If possible, the wind pressure should

be utilized, safely avoiding all such parts at which depression or partial vacuum may occur in flight. The installation drawing at Fig. 505 gives all important dimensions and an outline of the engine. The dotted lines at the base of the engine show the position of the starter and gear.

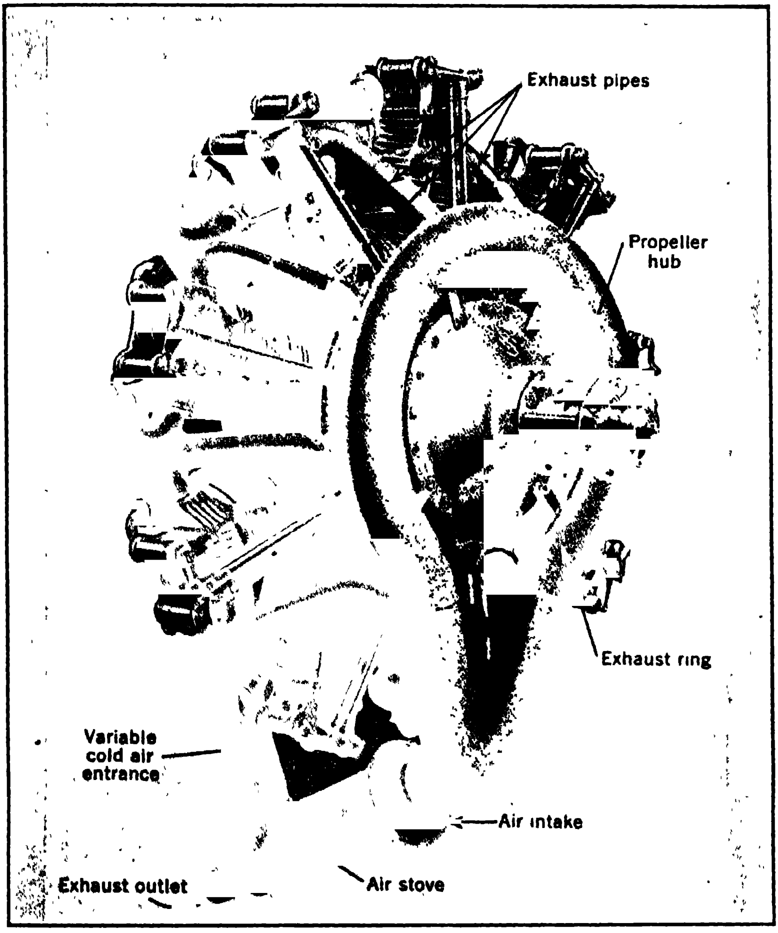
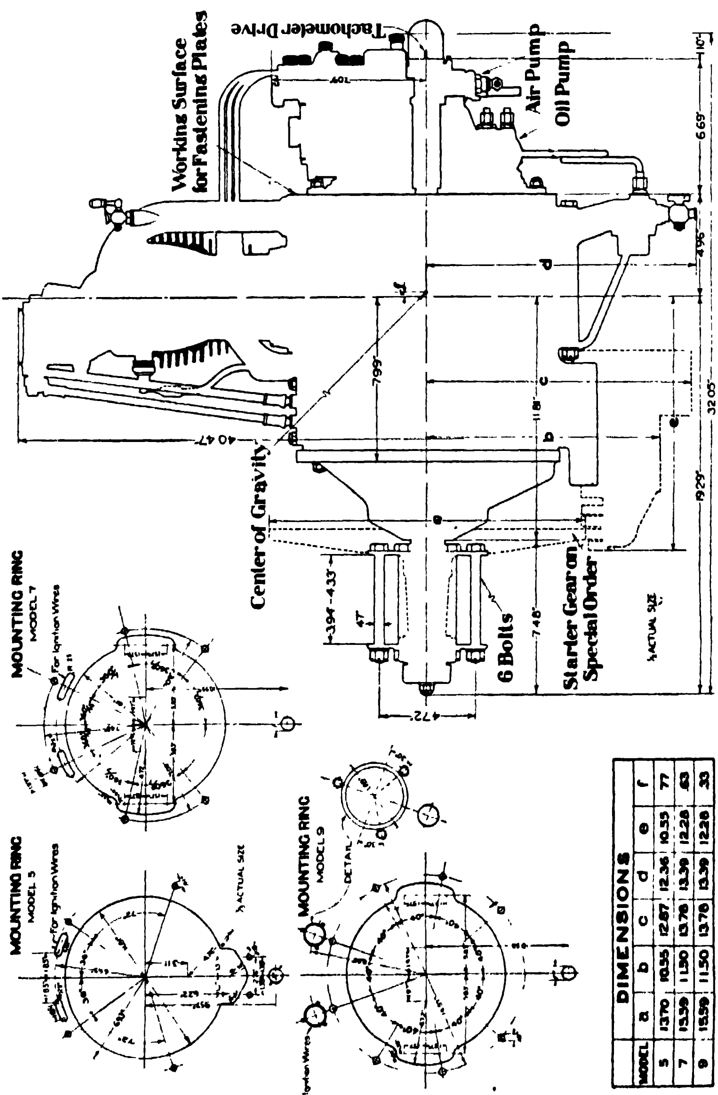


Fig. 504.—Siemens-Halske Radial Air-Cooled Engine Type Sh. XII, with Exhaust Collector, Air Preheater and Starter Base.

It is always desirable for aerodynamic reasons to partly encase the engine with suitable cowling thus reducing the air-resistance. The advantage afforded by such a casing is that the engine, for the greater part, is protected against the head wind and that, accordingly, the thermal conditions of the engine do not vary nearly so much in summer and winter on the test bench and in actual flight, which renders the working conditions almost equal for all cases. A special form of cowling should be used, only

leaving the aluminum alloy cylinder heads uncovered. The makers and their sales agents are at all times prepared to give constructive advice upon installation and, therefore, invite enquiries upon all questions pertaining to engine fitting.

Exhaust Collector and Preheating Device.—On special request, Ryan-Siemens Radial engines are supplied with an exhaust pipe, shown at Fig. 504, simultaneously serving to preheat the air drawn in as well as to collect



DIMENSIONS

MODEL	a	b	c	d	e	f
5	13.70	10.35	12.87	12.36	10.35	.77
7	15.39	11.50	13.78	13.39	12.28	.63
9	15.59	11.50	13.78	13.39	12.28	.33

and discharge the exhaust gases. The exhaust collector affords the following advantages:

(a) The exhaust noise, the sharp report of which may inconvenience the pilot as well as the passengers, is considerably lessened.

(b) The whole airplane is more protected since a soiling of fuselage and planes by oil and soot is rendered impossible or greatly reduced.

Fig. 506.—Method of Installing Siemens Radial Air-Cooled Engine in the Heinkel Airplane. Note the Swinging Motor Mounting which Makes the Engine Accessible from All Sides. The Front End of the Fuselage Should be a Fire-Proof Bulk Head.

(c) The exhaust gases are conducted off outside the fuselage, the combustion gases no longer bothering the passengers.

(d) The air taken in by the carburetor heats up, the result being a better operation of the engine in the slow-running position, particularly winter.

(e) The primary air drawn in being well heated ensures a better distribution of gas to the various cylinders since precipitation of fuel within the distribution piping is avoided. This produces a steady running of the engine even at very low temperatures and is important for flying at great altitudes.

(f) A better mixture causes better combustion within the cylinders and thus prevents the sooting of the plugs, particularly when the engine is running without load and with the throttle only half open.

(g) No freezing of carburetor even at temperatures much below zero.

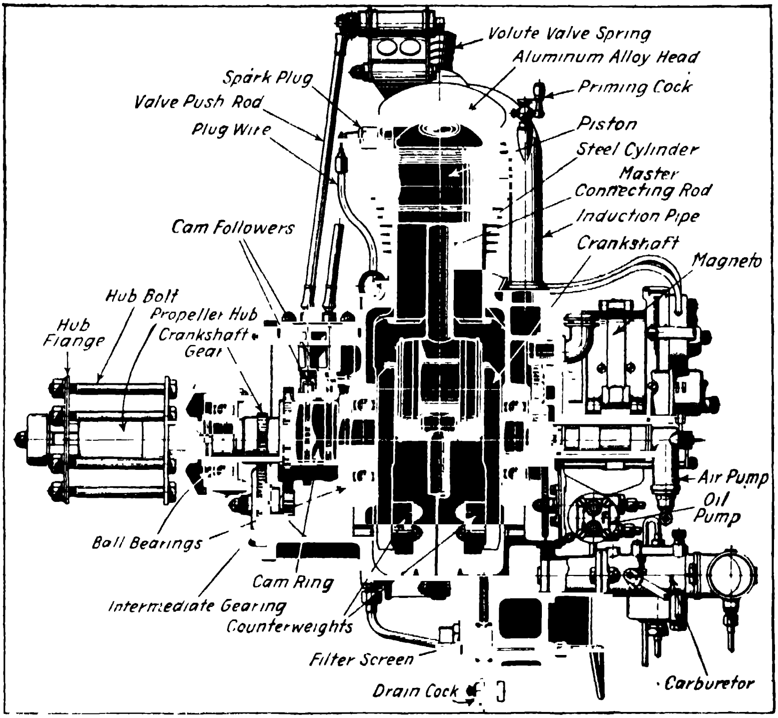


Fig. 507.—Sectional View of the Siemens-Halske Airplane Engine Showing Liberal Use of Ball Bearings Throughout.

General Description of Ryan-Siemens Engines.—The crankcase consists of two parts made of light metal casting. Front and rear ends are closed by a cover. The two halves which are provided with a centering flange meet at the center line of the cylinders in a face joint; and are held together by through-bolts. The outer rim of the rear cover serves for centering the engine on the plane. The ball-bearings of the crankshaft are installed in pressed-in and screwed bushings made of bronze. Special openings are provided in the front chamber for the guides, which are easily removed. The circular suction passage into which the suction pipes of the various cylinders run is cast-in in the rear chamber. The two magnetos as well as the oil- and

air-pumps are fixed on the rear cover and may be removed with same. The longitudinal cross sectional view of the engine shown at Fig. 507 shows the internal construction clearly, this showing the seven-cylinder engine which has no mixture distributing blower as the nine-cylinder shown at Fig. 508 has.

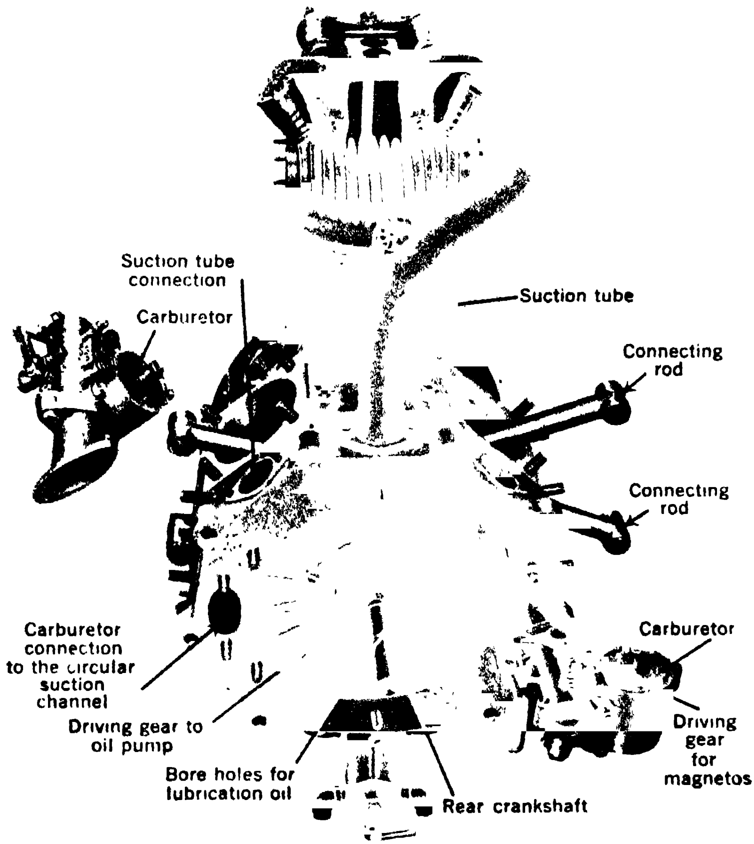


Fig. 508.—Rear View of the Nine-Cylinder Siemens-Halske Radial Engine Partially Dismantled.

The crankshaft is made from a high-class chrome-nickel steel forging. It consists of two parts and is hollow-drilled right through. The carefully balanced counter-weights provided on the crank-cheeks are held by means of cross bolts and centring. The rear end of the crankshaft having to transmit comparatively small power for driving the auxiliary apparatus is of correspondingly lighter construction. The two halves of the crankshaft

are connected by a slender cone with nut and dowel pin. The crankshaft consists of two parts for the purpose of fitting on the ball-bearings by way of which the master rod works on the crank. (See Fig. 509.) The design of the ball-bearings on the crankshaft is based on the result of extensive experimenting and the experience of many years and the usual method of mounting is clearly shown at Fig. 507 in sectional view. The shaft runs on ball-bearings on both sides of the crank-cheeks. A third ball-bearing (special type "Radiax") which also resists the screw thrust is provided in the front end-cover, the engine thus being suitable for pull- or push-screw arrangement. (See sectional drawing at Fig. 507.)

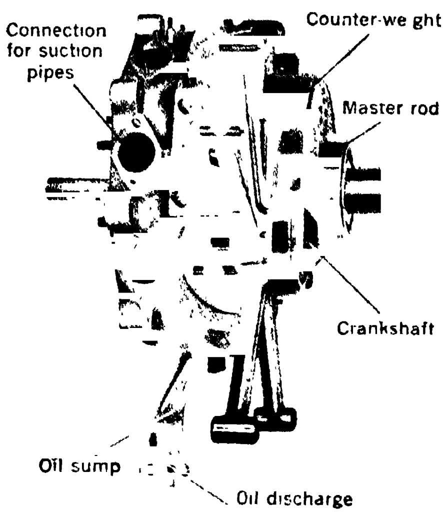


Fig. 509.—Crankshaft and Connecting Rod Assembly and Mixture Distributor of the Nine-Cylinder Siemens-Halske Radial Engine.

The tube-section connecting rods are made of high-grade alloy steel; they are very sturdy and exceedingly light. The connecting rod assembly consists of the master rod which is supported by the ball-bearings fitted to the crankpin and four, six, or eight link connecting rods respectively. These rods oscillate to and fro on wristpins in the bottom part of the master rod. Pressed-in bronze bushes secure a perfect running of the rod heads at the lower wrist and piston pins. All connecting rods are subjected to a very careful test with regard to equal weight and equal position of equilibrium.

The pistons are of aluminum alloy having bronze bushes for piston pins. These pistons are based upon extensive experience. Two packing rings and two oil scraper rings serve to prevent any considerable loss of pressure and warrant perfect lubrication. Each piston ring is tested as to its tensile strength. The piston pin is movable and suitably secured against lateral

dislocation by means of spring rings. The pistons are also tested as to equal weight, this resulting in a practically perfect balance of masses and steady running of the engine.

The cylinders which are shown at Fig. 510 consist of an alloy steel sleeve open at the top, with screwed-on aluminum alloy heads secured against dislocation by a shrink ring and jam nut. The combustion-chamber is hemispherical. The intake and exhaust valves are fitted side by side, in a position diagonal to the direction of flight. They are operated by push rods and rockers. The latter are run on rollers and carried in a plate bridge

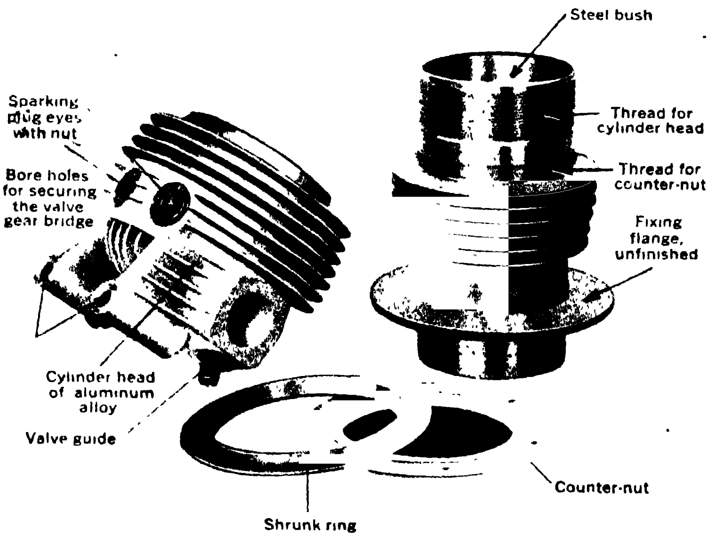


Fig. 510.—View Showing Cylinder Construction of the Types Sh. 10, Sh. 11 and Sh. 12 Siemens-Halske Engines.

consisting of welded plate and fixed to the cylinder head by bolts. Bronze alloy seatings are inserted from the interior of the cylinders and secured by nuts. On account of their peculiar design the volute valve springs will stand the maximum strain. The valve stems run in case-hardened steel guides shrunk into the head and secured by nuts. The arrangement of the valve rockers is clearly shown at Figs. 507 and 512, the latter view showing the top of the cylinder head.

The crankshaft operates the cam drum by means of intermediate spur gears shown at Fig. 515 and in sectional view at Fig. 507. The roller tappets are carried in bronze bushes inserted in tappet guides of aluminum alloy. The hollow drilled interior contains a long spring preventing the thrust rods from falling out should a valve have gummed up and stuck open. The tappet guide construction is clearly shown at Fig. 511

The intake valve opens in accordance with timing diagram shown at Fig. 513, six degrees before top dead center and is closed 48 degrees after

bottom dead center. The exhaust valve opens 48 degrees before bottom dead center and is closed six degrees after the top dead center. Thus the timing is symmetrical to the dead centers of the piston. The ignition advance is 34 degrees. With a cold engine, the timing marks provided on the casing are available only with a valve stem clearance of .8 millimeters.

The auxiliary apparatus and the air exhaust system are installed on the rear cover. The exhaust system is provided with a pipe screw plug, whence a pipe is conducted outside the engine casting for the purpose of carrying off the oil vapors. Sturdy double-wall sockets are provided for both Siemens magnetos, in addition to one flange and four stud bolts which are

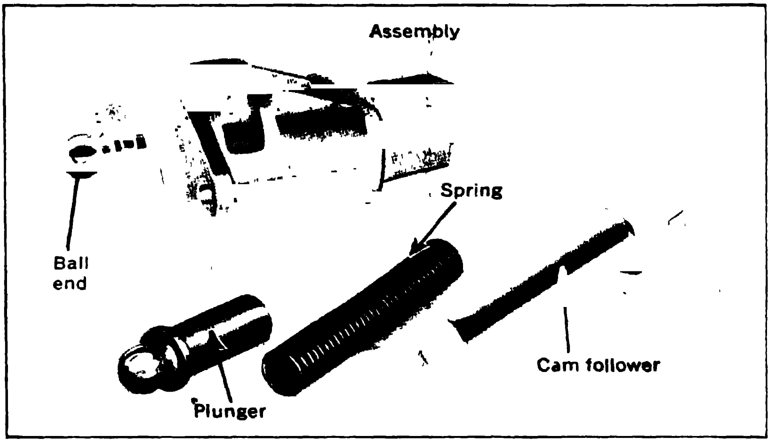


Fig. 511.—Views Showing Tappet Guide Made of Aluminum Alloy.

supplied for fixing the oil pump. The driving shaft of the magnetos is provided with the driving gear. A flange carries the accessory ball-bearing and is fixed together with the magneto. The crankshaft runs in a tube-shaped cap, both air pump and revolution meter drive being installed at its rear end. The cover may be mounted as a complete unit, together with all auxiliary apparatus as shown in the views at Fig. 514, the view at the left showing the rear end cover outside, that at the right illustrating the inside of the plate or cover.

Although the engine is easily started by hand it may be desirable to start it from the pilot's seat without the assistance of a mechanic, for which purpose the Siemens Radial engines are fitted, on special request with an electric starting device, the gear of which is brought into mesh with a large diameter spur gear to be mounted on the propeller hub. In this case the engine is set running just like that of a car by means of a push-button.

Fuel and Lubrication Systems.—The fuel should be supplied to the carburetor through a feed and filter by way of an eight by ten millimeter supply pipe of copper at a minimum head of twenty centimeters. If the flow is insufficient the gasoline tank will have to be put under pressure by the hand and engine air-pumps. The fuel recommended by the makers for

these engines is pure gasoline of a specific gravity of .7 to .7255 or pure benzol of a specific gravity of .865 to .870 or both in various proportions as mentioned in the chapter on fuels. Of course, aviation gas suited for other engines will be suitable for this one. Only use clean approved fuel and avoid using unapproved mixtures.

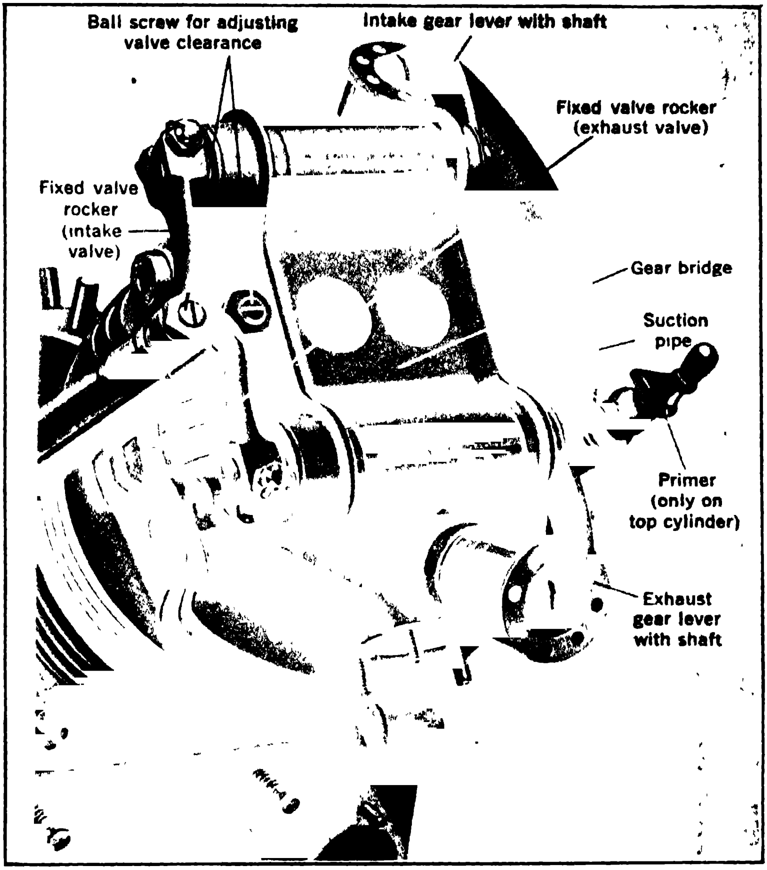


Fig. 512.—Cylinder Head of Siemens-Halske Engine Showing Valve Gear.

The oil circulation is automatically effected by a gear pump, the case of which is made of aluminum alloy and attached to the rear end cover. The pumping gears are driven from the crankshaft by way of the driving pinion of the oil pump itself and a worm gear inside the pump case which latter reduces the number of revolutions to 1/11. A pump is provided on each side of the worm gear, consisting of a driving gear and a driven gear. The scavenger pump capacity is twice as high as that of the fresh oil pump, the performance of the former amounting to twice the quantity delivered by the fresh oil pump, which guarantees the crankcase to be always free from oil. At the rear end of the pump case a pipe connection is provided

to which the hand pump is connected over a retaining valve. Previously the hand oil pump was supplied according to arrangement a (see Fig. 516) where it had to be refilled with the oil can, but now arrangement b is preferred. This pump taps the main pipe behind the large oil filter, the oil being drawn in automatically by the pump piston. The hand oil pumps serve to fill the pipes if it is desired to increase the supply of lubrication oil occasionally, or after a long period of inactivity.

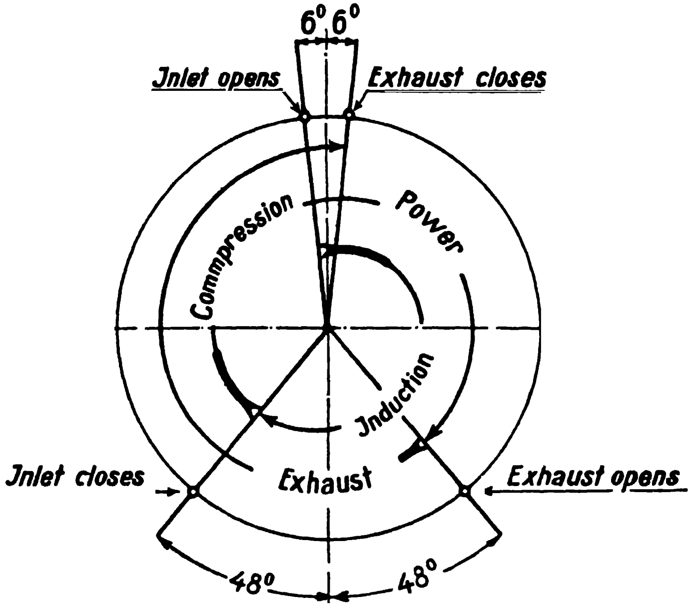


Fig. 513.—Timing Diagram of Siemens-Halske Engine.

The hand pump connection on the casing of the oil pump is conducted into the interior of the pump case, the latter being connected with the pressure side of the fresh oil pump. This connecting bore-hole effects

1. a constant supply of fresh oil to the pump case with the cross drive and furnishes,
2. the possibility of supplying oil into the fresh oil delivery piping by means of the hand lubricator.

The feed and scavenger pumps are readily accessible and can easily be cleaned on taking off the respective covers. Each cover is provided with a hole for a dowel pin in order to avoid confusion when replacing it, and in addition both covers are lettered and marked with arrows to indicate the direction of supply and function of each pump, "F" signifying fresh oil pump, "R" scavenger pump.

To ensure efficient suction every care must be taken that the pressure pipe mouth of the scavenger pump in the oil tank is kept well below the oil level. For this reason it is essential to conduct, above the oil level, a

stand pipe of eight to ten millimeters interior diameter with a three millimeter lateral bore-hole slightly above the oil tank bottom, in which case the oil is fed through the side hole up to the double-tube cock, while the ascending pipe ensures a thorough mixture of both oils (see diagram Fig. 516, bottom right-hand corner). The double pipe cock simultaneously frees the oil piping from tank to engine as well as the piping from oil sump to tank, whereby oil is fed to the pump gears and suction secured.

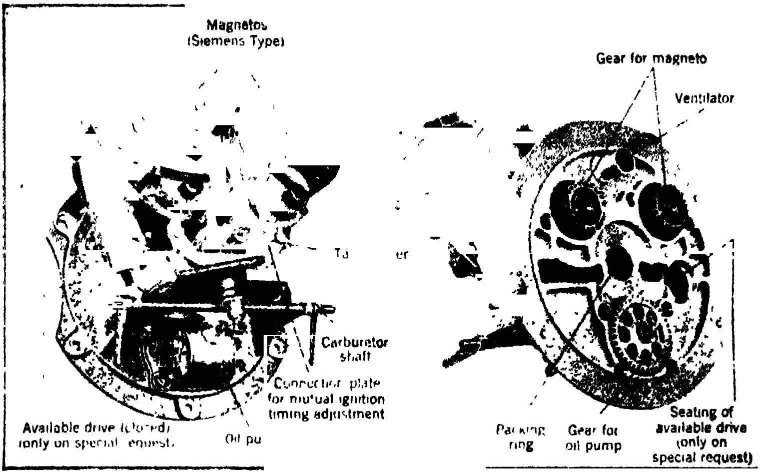


Fig. 514.—A Shows Outside View of Siemens-Halske Rear End Cover with Ignition Magnetos in Place. B Shows Inside View of Rear End Cover.

The pump is fed from an oil tank by way of a double-pipe cock and filter. It presses the oil into the engine, draws it from the sump through a filter and forces it into the tank. The oil supply may be effected from an elevated tank installed so as to give a slight positive head of at least twenty centimeters between bottom edge of tank and pump connection. (Copper tube of fourteen millimeter interior diameter decreasing to six or eight millimeter diameter just before it is introduced into the pump.) If there is not sufficient head the oil tank will have to be put under pressure by connecting it up to the hand air pump as well as to the engine pump. The pipes should be run in accordance with the oil diagram.

In the engine itself the oil flows from the pump into the oil chamber or bush which is pushed over the rear main crank journal. By way of the holes the pressure oil passes through a filter and the hollow crankshaft on to the crankpin where it spurts from small holes on to the wristpins and crankpin bearings. The cylinder walls, the pistons, connecting rod ball-bearings and crankshaft bearings are adequately lubricated by the circulating oil. Part of the oil is supplied to the gear case, where it lubricates the pull- and push-bearing, the bearings of the cam drum as well as the tappets. All the oil draining off is collected in the oil sump (see Fig. 515) where it is drawn by the pump through an easily removable oil filter and returned to the tank. This filter as well as the screen contained in the rear crankpin

should be cleaned at frequent intervals. This also applies to the large oil filter to be fixed between oil tank and pump.

The lubricating oil recommended for this engine should comply with the following conditions: It should be pure mineral oil, free from fatty oil, tar oil or foreign matter. Specific gravity of .9 to .93 at fifteen degrees Centigrade. Flashpoint about 200 degrees Centigrade. Viscosity ten to fifteen Engler degrees at 50 degrees Centigrade. Maximum acidity .07 per cent. Clearly soluble in standard gasoline. Loss not to exceed .4 per cent after two hours heating. New formation of asphalt-like substances not to exceed one per cent. Maximum percentage of ash .04. Oil recommended: Gargoyle B and BB, Ossag-Aero-Voltol (German) or Castor Oil.

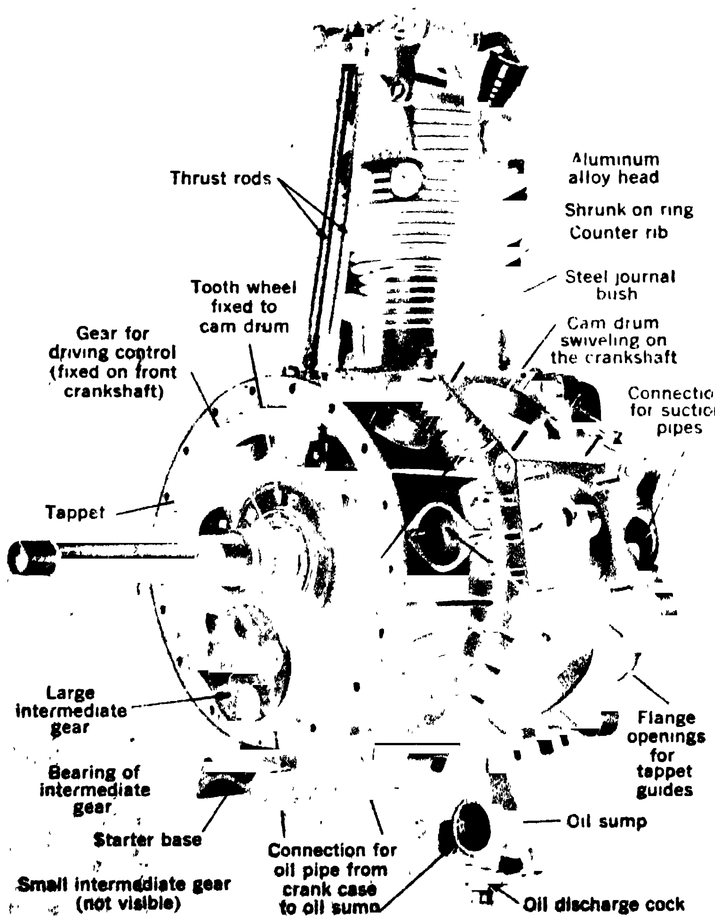


Fig. 515.—Partially Dismantled Engine Showing Valve Drive Gear of Siemens Sh. 12 Model.

Above specifications only apply to the frostless season. For temperatures below zero noncongealable oil should be used, complying, in general, with the conditions specified above, but with a solidifying point of -12 to -25 degrees Centigrade. Gargoyle Arctic and Ossag-Aero-Voltol have proved very good. If the oil congeals the oil tanks and piping have to be cleared after each run so as to insure a perfect lubrication. In that case, do not forget before starting the engine, to fill the tank with oil suitably heated up and refill oil piping with the aid of a hand pump.

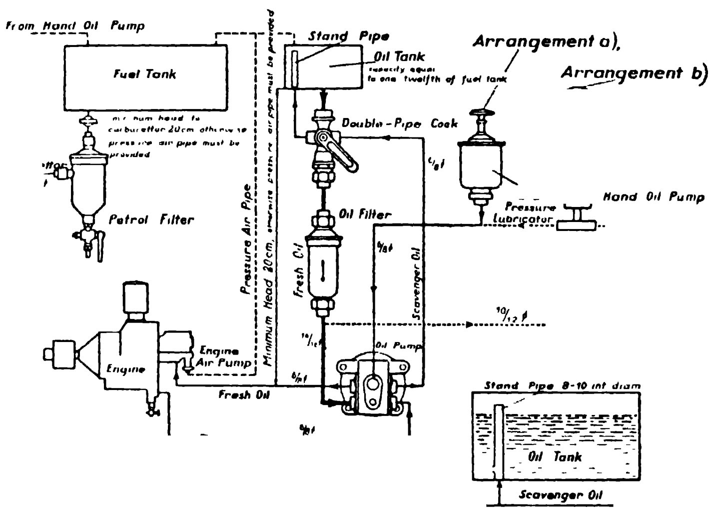


Fig. 516.—Diagram Showing Suggested Fuel and Oil System for Siemens-Halske Engines.

Ryan-Siemens Ignition.—Ignition is effected by the highly approved Siemens Sparkplugs, Types U2 or U3 specially designed for air-cooled engines of a high compression ratio, and by two Siemans H.T. magnetos (types F5, F7, F9, or EF5, EG7, EG9) working independently from an electrical point of view. In accordance with the number of cylinders the figures one to five, one to seven or one to nine are provided beside the cable terminal screws. The cable ends show corresponding figures. With four-stroke radial engines the ignition should always skip one cylinder. With the cylinders numbered in accordance with the rotation of the propeller and the top cylinder marked one, the firing order of the three engine types is as follows: Five cylinders: 1 3 5 2 4, Seven cylinders: 1 3 5 7 2 4 6, Nine cylinders: 1 3 5 7 9 2 4 6 8.

The figures on the cable terminals of the magnetos indicate the ignition order of the latter. Thus, the plug connected with terminals 1 fires first to be followed by the plug connected with terminals 2, etc. Hence, with the terminal 1 connected to the plug of cylinder 1, terminal 2 will have to be connected with the plug of cylinder 3, and terminal 3 with cylinder 5, etc. The cable connections for all three engine types are illustrated in the wiring diagrams given at Fig. 517. These diagrams show that all plugs in the

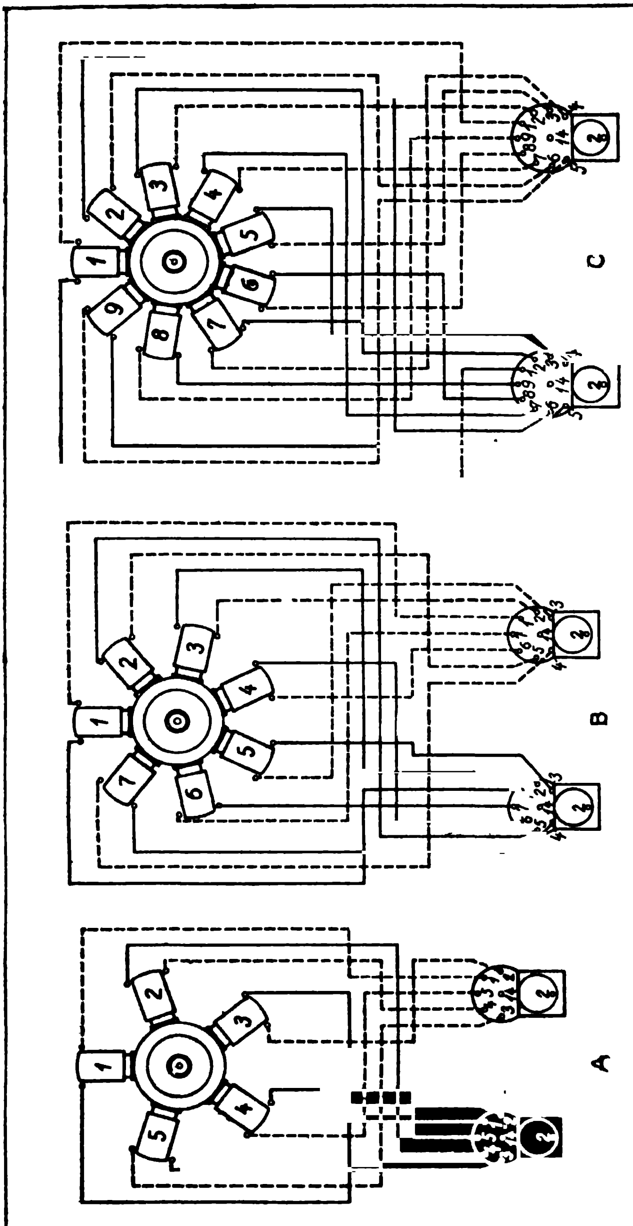


Fig. 517.—Wiring Diagrams for Ignition of Various Models of Siemens-Halske Engines. A—Five-Cylinder Sh. 10. B—Seven-Cylinder Sh. 11. C—Nine-Cylinder Sh. 12.

direction of the crankshaft rotation are connected with one magneto and those lying in the opposite direction with the other. The cables are correspondingly arranged in the cable duct supplied with the engine. By using two separate ignition systems all possible plug disturbances are easily localized with the aid of the switch.

The engine is started either by means of the crank handle starter or by an electric starting motor.

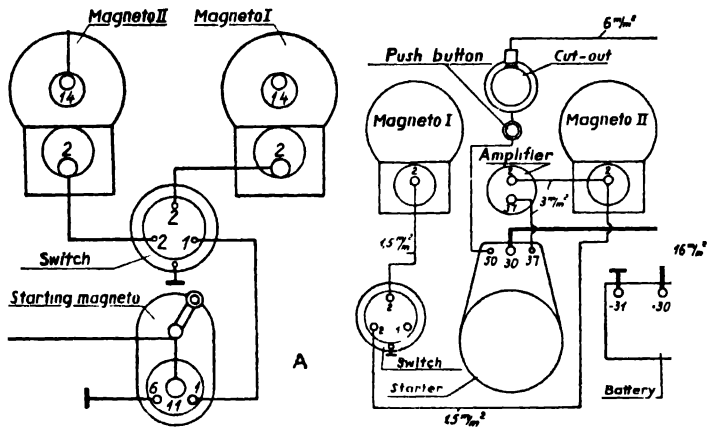


Fig. 518.—Wiring Diagram for Crank Handle Starter is Shown at A. Primary Wiring Diagram for Electrical Starter is Shown at B.

(a) Diagram A, Fig. 518, applies to the crank handle or booster magneto starter. The starting magneto serves for starting the engine from the pilot's seat after a combustible mixture has been fed to the cylinders. By quickly rotating the crank handle of the booster or starter magneto heavy sparks are generated. The cable connecting terminals eleven and fourteen conducts the H.T. current over the magneto distributor of the plug belonging to the cylinder whose piston is performing the working stroke. As soon as the engine begins to run a further rotating of the crank handle is useless since ignition is now effected by the regular magnetos.

After setting the magnetos correctly and coupling them to the engine connect as follows:

1. Terminal 1 on the starting magneto with terminal 1 of the commutator.
2. Short-circuit terminal 2 on magneto M1 with the terminal 2 on the commutator and the other terminal 2 on the commutator with the short circuit terminal 2 of magneto M2.
3. Distributor terminal 14 of magneto M2 with terminal 11 on starting magneto.
4. Terminal 6 (ground) on the starter with engine body and the latter with body terminal of commutator.
5. The sparkplugs of one cylinder side or group with M1 distributor

according to the diagrams at Fig. 517 and those of the other cylinder side or group with M2.

Commutator or switch positions are: O--Working magnetos and starting magneto switched off, M_1—Working magneto 1 and starting magneto switched on, M_2—Working magneto 2 and starting magneto switched on, 2—Working position: working magnetos 1 and 2 and starting magneto switched on.

By setting the commutator handle or switch lever to zero the primary circuit of the magnetos is shorted and ignition interrupted. When pointing to zero, the commutator handle is easily removed whereby an unauthorized starting of the engine is rendered impossible.

For the electric starter which is only supplied on special order see wiring diagram, Fig. 518 A. The electric starting motor enables the pilot to start the engine from his seat without the assistance of a mechanic. When the push-button is pressed with the engine standing idle, the battery current is conducted through the starter, the pinion of which is automatically brought into mesh with the corresponding large diameter spur gear on the propeller hub thus setting the engine running. The starter is wired so as to render mechanical disturbances in the gearing impossible. The amplifier or induction coil produces heavy sparks during the slow rotation due to the starting motor. The following battery is recommended for the starter: Two accumulators, six volts each; weight 12.5 kilograms each or 25 kilograms or 55 pounds Dimensions of each accumulator: height 212 millimeters, length 155 millimeters, width 130 millimeters.

Connect as follows:

1. Terminal 31 (—) of battery with ground.
2. Terminal 30 (+) of battery with one terminal of the fuse.
3. The other terminal of the fuse with one terminal of the push-button.
4. The same terminal of the push-button with starter terminal 30. Use only heavy gauge starter cable capable of carrying heavy amperage of starting current.
5. The other terminal of the push-button with starter terminal 30.
6. Starter terminal 37 with amplifier terminal 37.
7. Amplifier terminal 2 with short-circuit terminal of magneto 2.
8. The same terminal 2 of magneto 2 with commutator terminal 2.
9. Commutator terminal 2 with short-circuit terminal 2 of magneto 1.
10. Ground terminal of commutator with the ground.

The various positions of switch handle are: 0—Magnetos off, M_1--Magneto 1 and starter on, M_2—Magneto 2 and starter on, 2—Working position: Magnetos 1 and 2 and starter switched on.

Starting the Engine.—It is absolutely essential to fix a special plate near the revolution meter on the instrument board reading as follows: "Use hand oil pump before starting engine." Bear in mind the following when starting the engine: Only allow engine, after a long period of inactivity to reach the working conditions slowly. The engine should not be called upon to give full power before perfect lubrication is assured and an adequate thermal condition attained. Hence, after a long stand-by (exceeding three hours) the piping should be filled up with a hand oil pump in order to

secure immediate automatic lubrication. Let engine run slowly for about one minute, gradually advancing to full power in the second minute. In doing this moderately assist lubrication with hand pump until engine begins to emit smoke. If the engine is connected up according to diagram at Fig. 516 check the following: 1. See that fuel and oil tanks are filled up. 2. Put oil and fuel tank under pressure by means of hand air pump. 3. *Turn on double pipe cock.* 4. Shut off gas throttle. 5. Turn on fuel cock. 6. *Do not forget to feed hand oil into pipes.* 7. Set spark lever to retarded position. 8. Short circuit ignition. (Zero position on switch.) 9. Pull engine over *sharply* several revolutions injecting just a *few drops* of fuel (gasoline or ether) in top suction pipe. 10. Turn off primer. 11. Open throttle but a little. *For crank handle starter*: 12. In reply to order "ready" set commutator to position 2 and sharply turn starter until engine begins to run. *For electric starter*: In response to order "ready" push button until engine begins to run. 13. Spark lever in advanced position. 14. Slowly advance to full throttle position. In doing so lubricate *sparingly with hand oil pump.*

If the engine fails to function the mixture in the cylinder has probably become too rich owing to frequent priming. Should this prove to be the case pull over engine several times in a counter-clockwise direction, that is, in the direction opposite to its normal rotation. By doing this air is amply supplied to the cylinders by way of the exhaust valves. Now try and start the engine again.

As soon as the engine begins to work set timing lever to full advance position. Carefully observe tachometer which with a full open throttle should indicate 1,500 to 1,750 r.p.m., according to the type of propeller employed. Check acceleration by repeatedly actuating the throttle. To check slow running completely close throttle. Under ordinary circumstances the engine should work faultlessly at about 500 r.p.m. and should not stop running. Try with the aid of the commutator whether the engine functions correctly on either of the two magnetos and check all plugs as to firing. Never attempt to take off before the engine proves to be in perfect working condition. Do not run the engine on ground, without load or with full open throttle, longer than absolutely necessary.

The engine should not exceed its maximum number of revolutions, viz., 1,750 r.p.m., the actual number always to be in accord with the work to be performed. It is for the pilot to see to that. Always keep an eye on the revolution counter during the whole flight. In gliding flights the throttle should also be opened occasionally so as to keep engine warm and plugs dry and free from soot. IN STOPPING THE ENGINE: 1. Close throttle. 2. Set commutator to zero. 3. Shut off gasoline and oil.

A key to perfect engine operation combined with flight safety is the selection of a suitable type of propeller which should always be in full accord with the normal operating conditions and performances of the machine. Enquiries should be made with the airplane designers concerned. It is highly essential that the propeller is in proper balance. In cases of vibration while the engine is running, check the propeller and replace it by another, if necessary. Propellers which are not accurately balanced are a constant danger to the engine, and it goes without saying, that the engine makers cannot be held responsible for faulty engine action in such cases.

Dismantling the Engine.—To take down the engine proceed as follows, using the special tools provided with the engine. Place engine on mounting stand with the propeller hub end down as shown at Fig. 519. Take down carburetor and disconnect magneto ends of ignition cables. Remove oil pipes from oil sump to oil pump. Unscrew nuts on cover of magnetos as

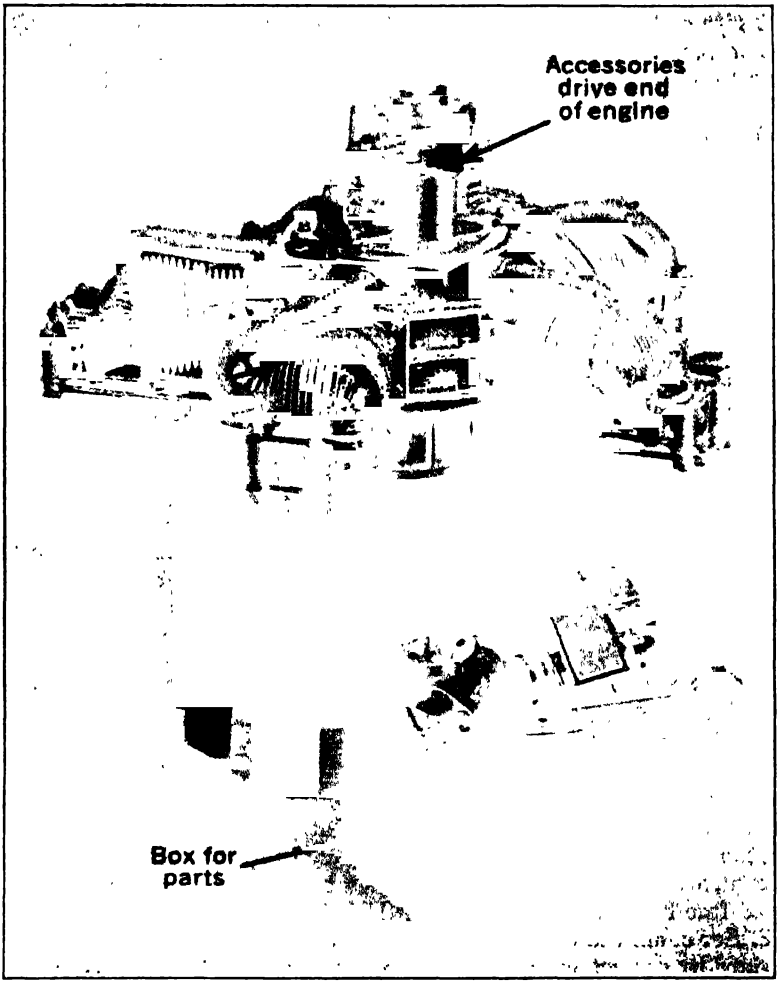


Fig. 519.—Siemens-Halske Engine on Stand at the Start of Dismantling Process, Showing Suggested Method of Support.

well as the accessory spring. Open bridge plates. Take out magnetos and drive. Remove nuts on rear cover of casing. Take off covers with oil and air pumps. Draw cables through case links. Remove suction pipes with aluminum flange and rubber ring. Screw off rear nut of cylinder flange (top nut with engine on stand) using special tool No. 9. The special tool

box is shown at Fig. 521 and a plate showing all tools is given at Fig. 522 to which the reader is referred. Remove sparkplugs with tool 19. Loosen valve springs by turning crankshaft with special tool 42 and remove push rods while pressing down rocker shaft. Take down front end cover. Remove key from crankshaft and end cover. Take off cable tube (Fig. 523).

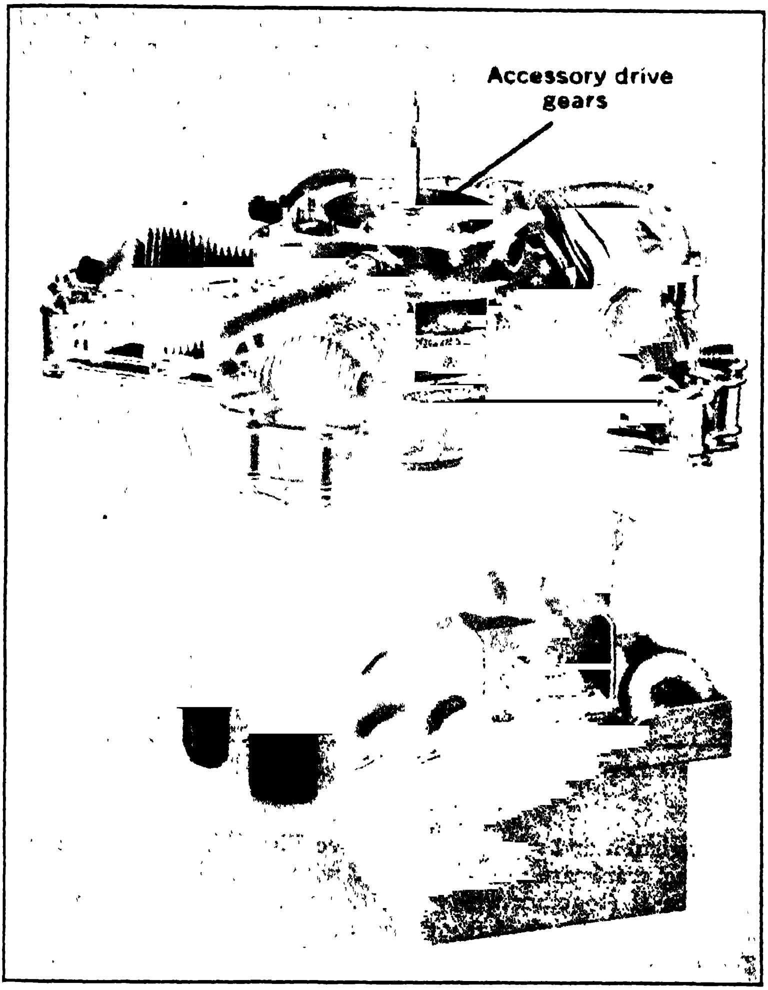


Fig. 520.—Siemens-Halske Engine with Induction Pipes and Part of Crankcase Removed.

Screw off the nuts of the front case cover. Put on lifter 18 for front cover. Reinsert crankshaft key. Put spanner 43 on ring nut and holding spanner 42 on crankshaft, turn bottom spanner to the left and top one to the right whereby the ring nut is removed from the crankshaft and the front cover simultaneously lifted off. To remove these parts take out crankshaft key.

Remove washer and distance tube. Take off nut in front of intermediate gear.

Pull off large intermediate gear with special tool No. 39, and in doing so, hold crankshaft as shown at Fig. 524. Remove ball-bearing cup intermediate gear with small tumbler gear. Apply lifting or pulling device 31 in accordance with illustration at Fig. 525 and remove control driving gear from crankshaft. Draw out all tappets and remove 1 and 3. Insert lifting device 31 under gear wheel rim on cam drum and remove the latter. Lift cylinders and, in doing so, turn crankshaft so as to make keyway on propeller taper seat of crankshaft point at the cylinder to be withdrawn. Remove retaining rings in piston bosses with the aid of a punch by gripping spring ring in back and springing them out of their respective grooves.

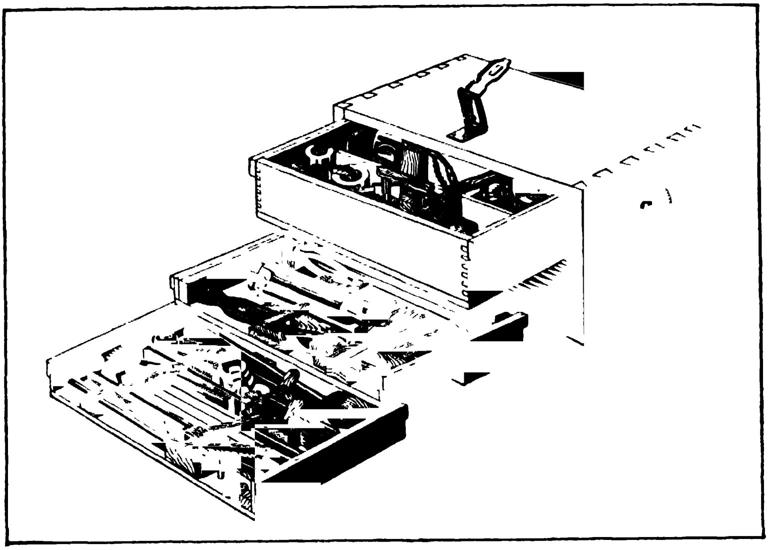


Fig. 521.—Tool Box Containing Special Tools Used in Overhaul of Siemens-Halske Engines.

Take out wristpin and remove piston. See Fig. 526. Remove screws and nuts, holding crankcase halves together with a special spanner 7. Apply lifting device 31 (together with 32) with pressure screw to crankshaft end and with grips on flange of front case and then separate casing as shown at Fig. 527. Take out crankshaft with bearings and connecting rods.

Detach front ball-bearing then take out tachometer drive. Draw out oil filter from crankshaft. Remove retaining lock ring of rear ring nut and ring nut itself. Take down rear ball-bearing together with gears. Put crankshaft in a vise according to illustration at Fig. 528. Remove spring securing crankpin ring nut and take off the ring nut with special spanner 41. Place strut into hollow crankshaft. Screw special removing tool 21 into thread of front crank cheek and separate crank halves. Withdraw master rod leaving one ball-bearing in the rod, the other on the pin.

Assembling the Engine.—Special note: Clean each part thoroughly. Examine all securing parts such as nuts and bolts, screws, etc., and see that none are missing. Do not assemble moving parts in a dry condition, be sure to lubricate liberally with a hand oil can before replacing parts which have motion relative to each other. Carefully push master rod on to crank pin. Do not break oil retaining rings or press them out of the slots. Force master rod on the pin ball-bearing, carefully driving it on with the aid of a

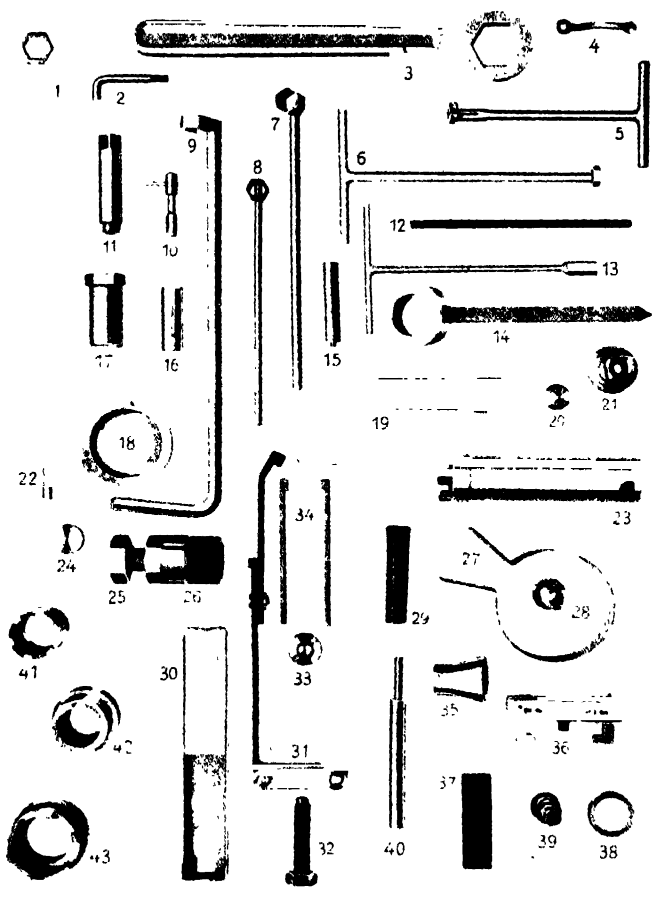


Fig. 522.—Illustration Showing Special Tools Used in Dismantling and Assembling Siemens-Halske Engines.

wooden hammer. Insert second ball-bearing Push the two crankshaft halves into each other and pull up tight with ring nut. Secure ring nut. Put rear ball-bearing on shaft and fix spacing ring. Secure rear gear with key and ring nut and secure the latter with retaining ring. Rest rear half

of the casing on the block with dividing joint uppermost. Insert crankshaft. Place connecting rods in correct position, the master rod always running in cylinder 1 (top cylinder). Fix front ball-bearing in front case. Put front casing on rear casing without packing. Connect casing halves by bolts and nuts.

Put piston on rod. Replace the various pistons into the right cylinders, viz, those in which they have been running previously. Cylinders and pistons are marked, the former on front edge of flange, the latter on the bottom above the eye. Do not forget to reinsert retaining rings in piston bosses after replacing the piston wristpins. Insert spring ring so that the beginning of the ring is kept five millimeters behind the groove in the eye of the piston bolt. See that piston rings are properly installed as shown at Fig. 529. Top rings 1 and 2 are straight rings, while 3 and 4 are beveled and are installed with the bevel uppermost.

Do not forget paper packing when replacing the cylinders. Pull cylinder nuts up tight and fix split pins. Push valve tappets out. Do not yet secure tappets 1 and 3 in crankcase since otherwise the cam drum is brought to bear upon the tappets. Turn crankshaft until the key for the small tooth wheel on the crankshaft points exactly to cylinder No. 1. (T.D.C.) See Fig. 530. Place cam drum on crankshaft with the center between inlet and outlet cams (marked M) pointing exactly at the center of cylinder 1 and the tooth marked 1 downward (B.D.C.). Fix small intermediate gear with keyway pointing upwards so as to bring tooth 1 of the cam drum gear between the gear teeth marked 1, 1. Put gear on crankshaft with tooth 11 pointing downward (B.D.C). Fix large intermediate gear so as to bring tooth 11 of the crankshaft into mesh with the teeth 11, 11 of the intermediate gear. Slip distance-tube and plate cap on to shaft. Put on front end cover with paper packing and pull up tight. Screw up ring nut in front of thrust bearing and secure with the aid of retaining ring or jam nut. Fix cable tube and insert push rods. The rocker clearances are set in the following manner: The marks on the casing are only valid for a warm engine. With the engine in a working condition, the clearance is .8 millimeter. Hence, with the engine cold, adjustment of the gear should also be made with a clearance of .8 millimeter. The marks are only available for all cylinders if that is the case. After adjusting all cylinders with the aid of the marks and with a clearance of .8 millimeter, the latter is everywhere reduced to .2 or .3 millimeter. It should be noted that the working clearance is automatically adjusted as soon as the cylinders begin to get warm.

Replace rear end cover and pull up tight. Put oil filter into shaft. Screw in tachometer drive (left-handed thread). Fix oil and air pumps. To time magnetos, both front and rear sides of engine should be readily accessible for the following operations. Have engine suspended, if possible, as shown at Fig. 531. Secure pointer on propeller cone with key and nut. Turn crankshaft to left and complete rotation until index points to VZ. (advanced ignition). The marks for the control points are cut into the flange rim of the front case. (See Fig. 530.)

Time magnetos so that the red mark on gear points exactly at red mark provided on casing. Bring the magneto thus adjusted into mesh with the driving gear in the engine. At first the magnetos should be secured on

the flange. Push magnetos out before fastening so as to give free play between flange and magneto, otherwise the driving gear is brought to bear upon the bearing ring. Connect ignition adjustment with plate bridge. For ignition and cable connections see diagrams at Figs. 517 and 518.

Special Tools for Ryan-Siemens Engines.—The special tools shown in Fig. 522 are as follows:

No. 1—Cylinder nut spanner
" 2—Removing tool for magneto and oil pump driving gears
" 3—Spanner for propeller remover
" 4—Spanner for contact breaker
" 5—Spanner for grinding in valves
" 6—Spanner for magneto flange
" 7—Spanner for connecting crankcase
" 8—Spanner for rear cover and for securing tappet guide
" 9—Spanner for screwing on cylinder nuts
" 10—Spanner for carburetor (jets)
" 11—Spanner for sparkplug seating
" 12—Rod for turning spanners 16, 19, and 29
" 13—Spanner for securing front end cover
" 14—Pointer for crankshaft timing
" 15—Bolts for pushing out connecting-rod pins
" 16—Spanner for valve-guide nut
" 17—Spanner for plug seating nut
" 18—Lifter for front cover
" 19—Sparkplug spanner
" 20—Stone for 21
" 21—Lifter for taking to pieces crankshaft halves
" 22—Spanner for gear bridge bolts
" 23—Spanner for securing nuts of gears on rear crankshaft
" 24—Stone for 26
" 25—Bolt for 26
" 26—Lifter for propeller
" 27—Piston ring clamp
" 28—Tool for pressing-in gear bridge bolts
" 29—Spanner for magneto gear nut
" 30—Valve lifter (see Fig. 532 A)
" 31—Lifter for cam drum and front case half
" 32—Bolts for 31 and 21
" 33—Stone for 31
" 34—Short shanks for 31
" 35—Tool for pressing out gear bridge bolts
" 36—Tool for removing magneto gears
" 37—Tool for ring nut in front cover
" 38—Washer for 30
" 39—Removing tool for intermediate gear of control
" 40—Mandrel for inserting valve guides
" 41—Spanner for the nut holding together the crankshaft halves
" 42—Spanner for crankshaft timing
" 43—Spanner for ring nut on front ball-bearing.

Ryan-Siemens Ignition Troubles.—The makers give the following procedure for locating engine troubles due to ignition: 1. **The engine fires back when being started.** Set timing lever to retarded position. 2. **The engine does not run up to full power.** See whether timing lever is in advanced position. 3. **Defective contacts.** The short circuit cable or plug leads are not properly insulated or may even be loose. Detonations or "back shots"

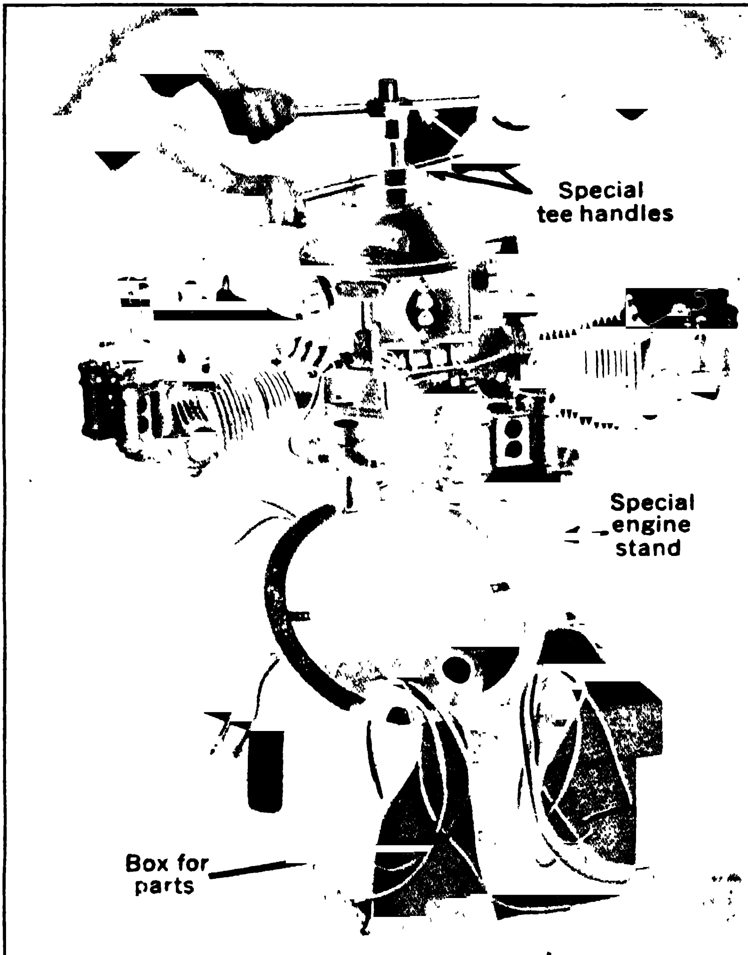


Fig. 523.—Removing Ring Nut from the Cam Drum.

in the exhaust collector or carburetor are noticed. 4. Wires are not conducted in accordance with wiring diagram. Magnetos clogged up with oil. Back firing in carburetor and ignition trouble will result from the foregoing 5. **Defective plugs: (a) Short-circuit between the electrodes:** This is due to the collecting of small metal particles between the electrodes, which

should be removed. **(b) The electrode clearance is too large:** The clearance should be adjusted with the aid of the gauge (.5 millimeter) supplied with each engine. **(c) The plugs are sooted:** The slow-running jet is too large (see carburetor). The engine is too cold and more preheating is required. The fuel is too heavy. A highly volatile fuel should be taken.

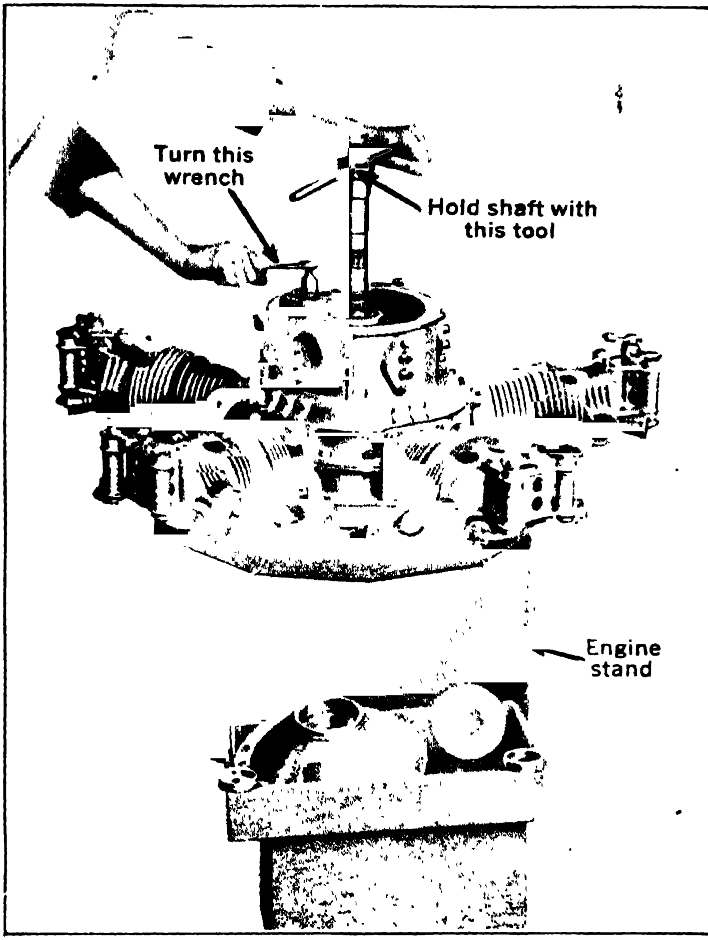


Fig. 524.—Method of Pulling Intermediate Camgear.

(d) The plugs are clogged up with oil: The plugs should be dipped into fuel and well cleaned which should also be done with sooted plugs. Run engine in the slow-running position with full open throttle for a few seconds. **(e) The plug packings are leaky:** These packings should always show an absolutely close fit since otherwise they may easily get red hot which is bound to result in self-ignition.

6. The platinum screws of the contact breaker show too small or too large a clearance or gap when opening. Most probably the contacts will be found gummed up. 7. The contact breaker spring is either loose or too weak which causes a jamming of the contact breaker. If the fiber bush on the contact breaker pin proves to have contracted and jams accordingly, this may easily be repaired by applying emery cloth of a very fine grain

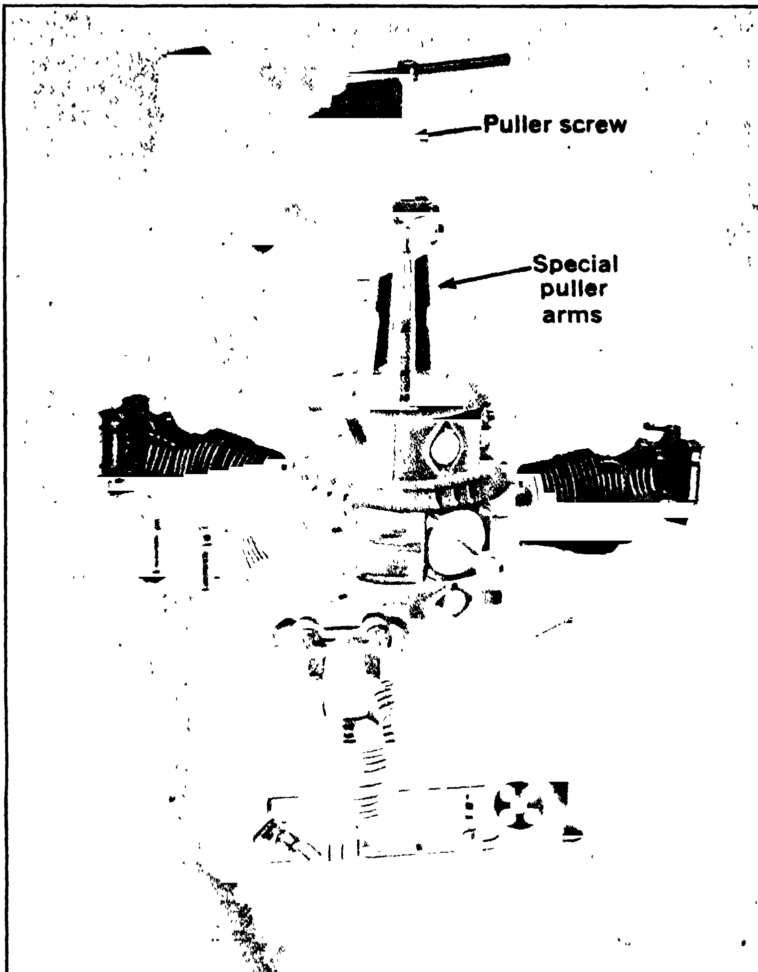


Fig. 525.—Use of Special Puller in Removing Crankshaft Main Bearings and Control Driving Gear.

and smoothing down pin a little. 8. The distributing lever or rotor is defective or clogged up. 9. There is a short-circuit in the magneto. This hardly ever happens, but should it really occur, the magneto should be sent to competent electricians for repair.

Carburetion Troubles.—The Ryan-Siemens engine makers suggest the following: 1. **Although the engine runs with the necessary speed of revolution in the slow-running position, yet its full-throttle performance is bad:** Insufficient supply of fuel to the carburetor. The filter is clogged up or foreign bodies are contained in the fuel feed or in the jets. 2. **The slow running is erratic:** Check the packings of the suction pipes as well as the rocker clearance. Very likely the slow-running jet is clogged up or too

Fig. 526.—How to Remove Wristpin Locking Rings from the Piston.

small. 3. **Large consumption of fuel:** (Black smoke is emitted by the exhaust pipe.) The main jet is too large or the compensating jet too small. **Insufficient full-throttle performance:** The main jet is too small or the compensating jet too large. **Slow-running regulation:** If the slow running is erratic or if the engine tends to stop running, this points to a lack of fuel.

Should the exhaust emit soot, though, there is too much fuel and the slow-running jet is, accordingly, too large. The slow running should be adjusted to 300 to 500 r.p.m.

4. **Detonations or Explosions in the Carburetor.**—The jets are clogged up thus only permitting small quantities of fuel to pass through. Water in the fuel. The engine is too cold. 5. **The carburetor runs over:** Leaky tip seating. Leaky float. The fuel filter is obstructed or blocked up with

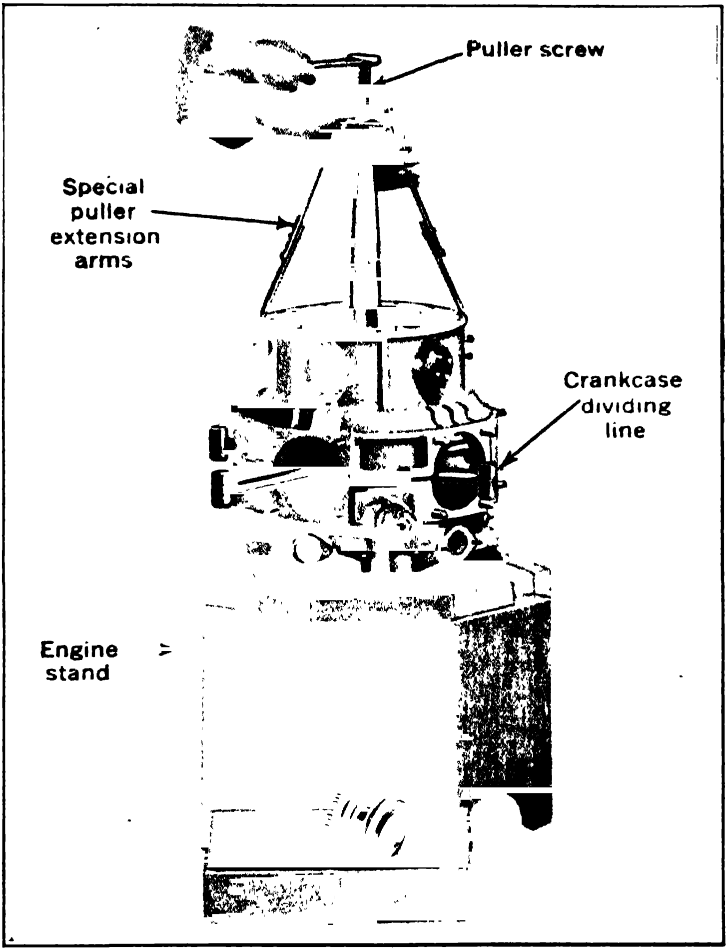


Fig. 527.—Illustrating the Use of Special Puller to Pull Crankcase of Siemens-Halske Engine Apart.

dirt. 6. **Engine gets too warm:** Poor mixture due to small jets. The timing lever has not been set to the advanced position. 7. **Engine emits smoke:** Black smoke is the result of too much fuel, in which case the slow-running jet is obviously too large. If the smoke proves to be of a blue color the engine is choked with oil. Run engine with full open throttle at short

intervals. 8. **Exhaust emits flames**: Fuel deficiency will result in long flames of a blue or violet color in the exhaust, whereas excess of fuel will give rise to short red or yellow colored flames. (As a matter of course, these colors can only be distinguished in the dark).

Lubrication Troubles.—Special attention should be paid to this item since a faulty lubrication is bound to do great harm to the engine. If anything is wrong with the lubrication system the speed of revolution will fall

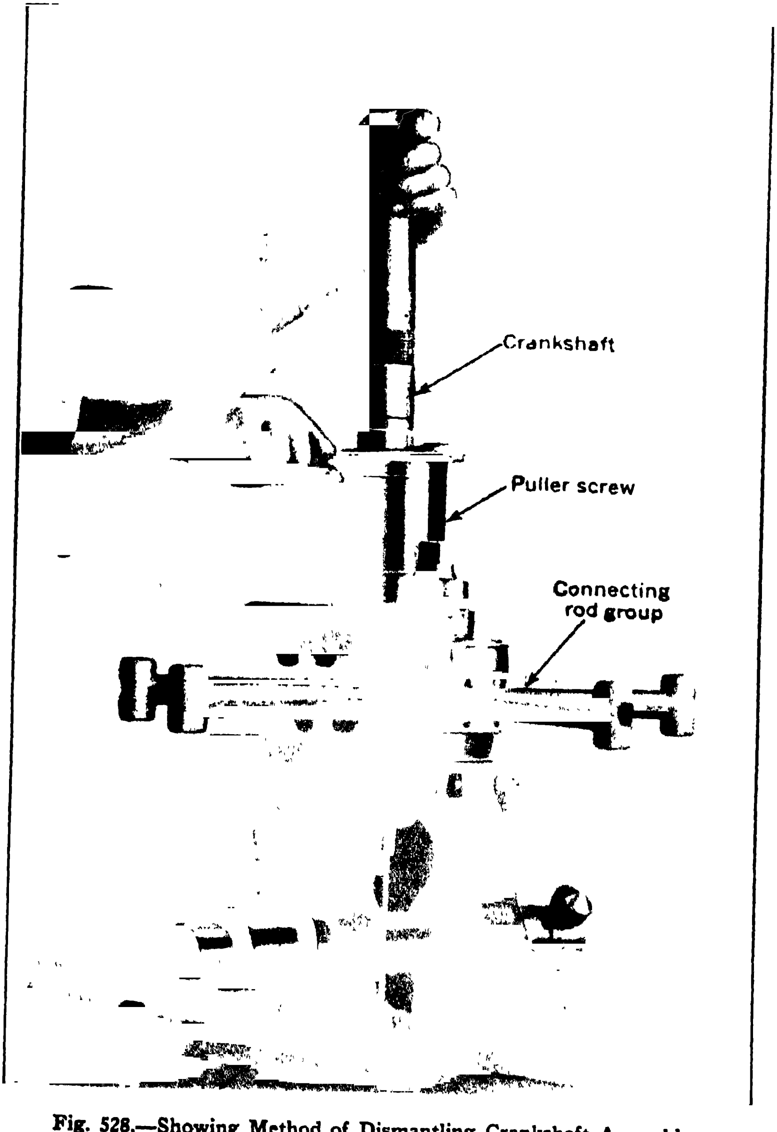


Fig. 528.—Showing Method of Dismantling Crankshaft Assembly.

off rapidly. Only oil complying with the specifications previously given should be used. 1. Insufficient head between bottom edge of oil tank and oil pump. Air pressure pipe is leaky or air pump fails to function. 2. The main oil cock has not been opened (double pipe cock). 3. Pipes or filters blocked up or leaky. 4. Faulty operation of oil pump. Remove pump, check it and have it thoroughly cleaned. 5. **Engine repeatedly choked with oil:** The scavenger pump fails to work. Remove cover and see whether the oil returns from the tank to the pump when the main oil cock is turned on. (See diagram Fig. 516.)

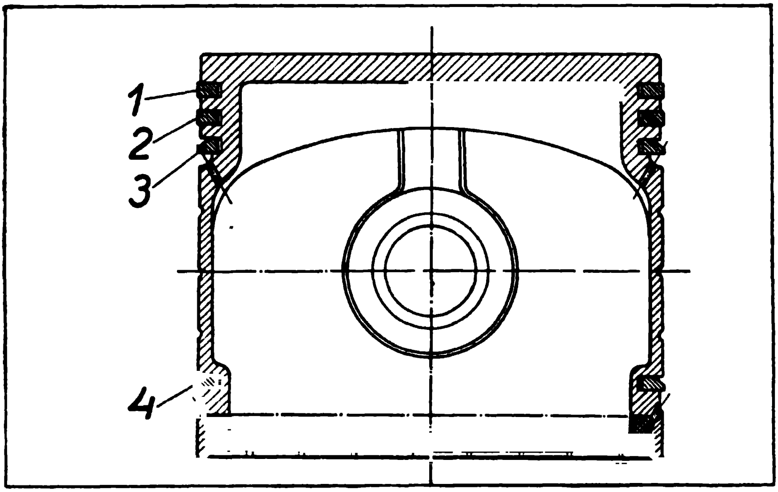


Fig. 529.—Sectional Drawing of Piston, Showing Proper Arrangement of Piston Rings. Note that Rings Nos. 3 and 4 are Bevelled and are Installed with the Bevel Uppermost.

Miscellaneous Troubles.—1. **Engine fails to start:** This may be due to a lack of fuel, to clogged-up jets or even to the presence of water in the carburetor (see fuel system diagram). The trouble may also be due to faulty ignition. 2. **The engine does not run up to full power:** See whether all cylinders are working. The valves do not close properly or the valve clearance is not correct. Jamming of piston rings due to the formation of carbon. 3. **Engine gets too hot:** See whether spark lever is in advanced position. Retarded ignition causes an excess of heat which latter may also be the result of faulty carburetion, too much air or fuel. 4. **The ignition fails:** The irrhythmical sound of the exhaust points to faulty ignition or carburetor (see above). The valves close very slowly or are jammed in the guides. Clean valve guides and valve stems with kerosene. If the valve has to be exchanged, the valve clearance will have to be adjusted again. Faulty ignition may also be caused by the presence of water in the fuel. The fuel should be filtered through a piece of chamois leather. The filter between carburetor and fuel tank is clogged up and permits but a small quantity of fuel to pass. 5. **The engine fires back:** The engine is too warm and pre-

mature combustion in the cylinder gives rise to advanced ignition which is not desired. The valves do not close properly or one of them is sticking. One of the plugs is defective. The magneto leads are not connected in accordance with the diagram or are shorted with the ground. Faulty carburction either due to an over-supply of air or an insufficient supply of fuel. Carbon may also have formed on the top of the piston or on the cylinder walls. As the result of an over-rich mixture the charge is still burning with the valves reopening. 7. **The engine is still rotating although the**

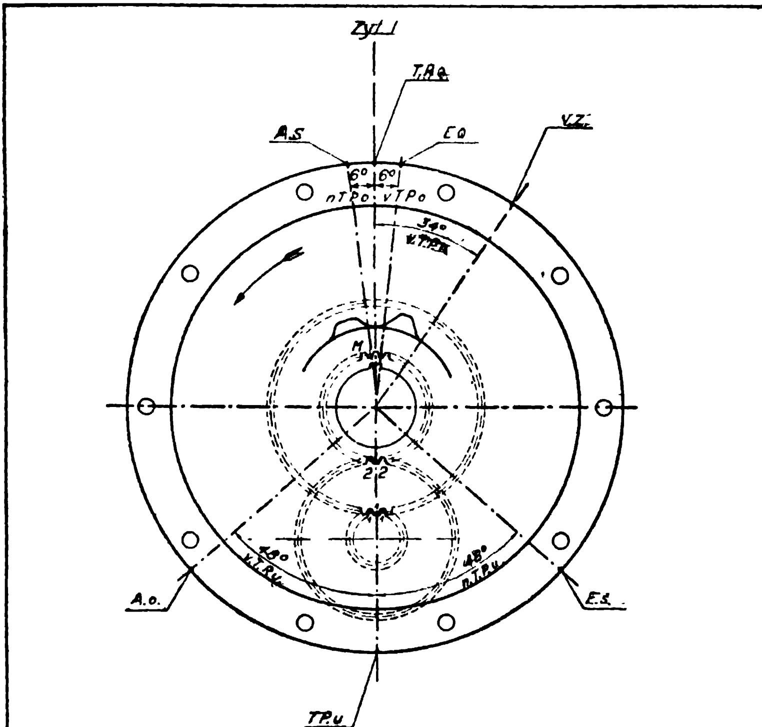


Fig. 530.—Diagram Showing Marks on the Crankcase as an Aid in Valve Timing in Siemens-Halske Engines.

ignition is short-circuited: The short-circuiting cable is out of order, which may also be the case with the short-circuit carbon in the magneto. The plug washers are leaky or the plugs themselves are overheated. All this is bound to give rise to self-ignition. Carbon particles glowing in the combustion-chamber. 8. **One of the cylinders fails to work:** Something is wrong with the plugs. The packing of the induction pipe leading to it proves leaky and permits the access of air whereby the mixture is weakened. One defective packing may already be sufficient to impair the entire carburetion and thus affect the operation of the whole engine.

Top Overhauls.—According to the general properties of the fuel employed as well as to the resulting condition of the engine, the cylinders should be lifted after an operation period of from 80 to 120 hours **and the** valves reground in, the piston tops as well as the interior of the cylinder head decarbonized and freed from a possible incrustation of soot and the

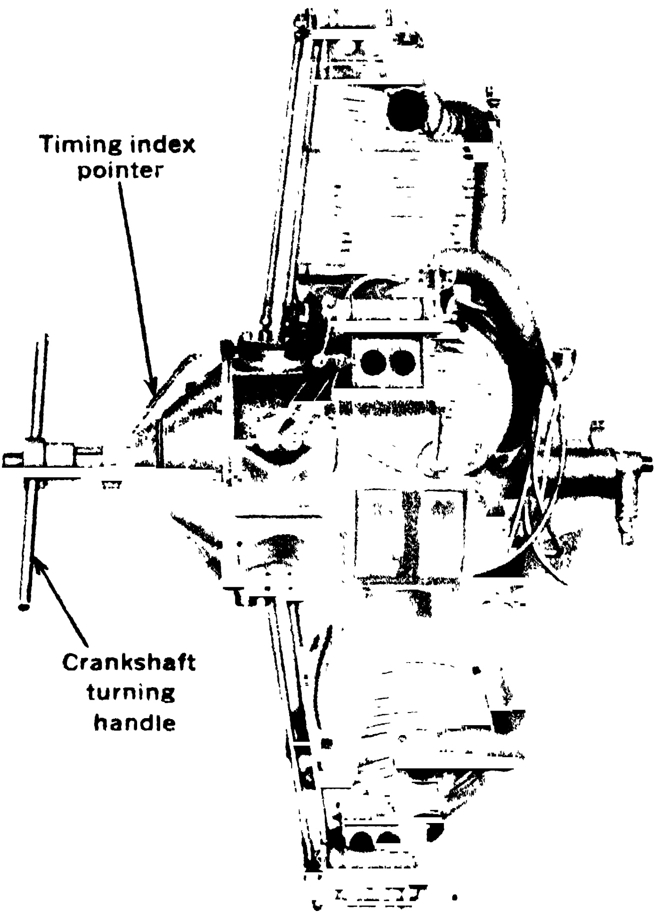
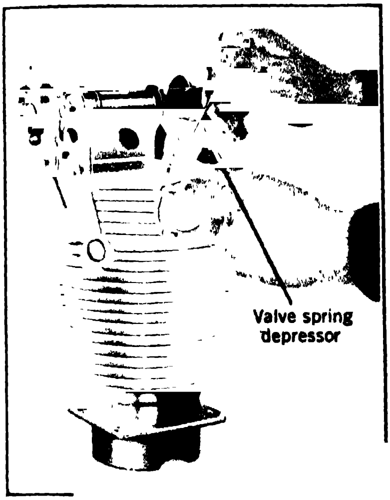


Fig. 531.—Showing Use of Valve Timing Index in Timing Siemens-Halske Motor Valves.

piston rings loosened in the grooves. The illustration at Fig. 532 A shows how to remove the retainer on the top seat of the valve spring. Fig. 532 B shows the way of **grinding in** the valves with the special tool. **The seats hardly ever require remilling** and, therefore, it should be **avoided. Only**

have them reground. The plug seatings as well as the bottom end of the aluminum alloy head may show signs of oil leakage. The illustration at Fig. 533 A demonstrates the way of tightening the plug seatings and the special tool needed. The illustration at Fig. 533 B shows how to secure the counter-rib at the top end of the aluminum alloy head by means of the corresponding special tools. Fig. 529, which has been previously described, shows the correct manner of installing the piston rings, and all pistons should be checked over when the cylinders are removed.



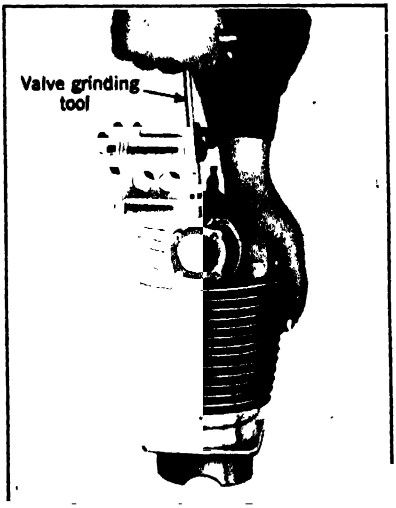


Fig. 532.—A Shows Method of Removing Valve Spring Retainer. B—Special Tool for Use in Valve Grinding.

The Carburetor.—The Sum Carburetor as used by Ryan-Siemans is tuned by choosing the correct jet sizes. The following nozzle jets are interchangeable: 1. The Sum nozzle stem (a) is an auxiliary carburetor in form of a multiple jet nozzle. This nozzle stem is provided with four fuel passages of a different size on the bottom conical side, which are marked at the head of the stem by figures corresponding with their respective sizes. These figures indicate in hundredths of millimeters the diameters of the jet apertures situated below, e.g., 165 means 165/100 millimeters diameter. This nozzle stem serves to measure the fuel supply required by the engine. In each case the figure facing the engine shows which jet is in operation. See arrow on nozzle stem cover. 2. An auxiliary air jet (compensating jet) is housed in the top part of the nozzle stem. The head of the compensating jet is provided with a mark showing the actual size. The figure provided slightly above the top air passage of the nozzle stem indicates the right way of adjusting the compensating jet. Compensating jets and nozzle stems may be replaced by others of a smaller fuel- or air-passage respectively. In order to fix both jets they are covered by a U-shaped spring cap. The latter presses both nozzle stems together on to the conical seating in the carburetor body. It is marked with an arrow indicating the

direction for reading the jet number.

3. The slow-running jet is housed in a special slow-running device. It consists of a four-edge nozzle body pressed into the slow-running device. Hence, there is a fuel passage for slow-running and four segmental air passages for the slow-running mixture. An immersion tube is screwed into the slow-running jet and projects into the spraying tube f. To clean the slow-running jet remove immersion tube. The slow-running jet can be exchanged, it is advisable, though, to take out the whole slow-running device.

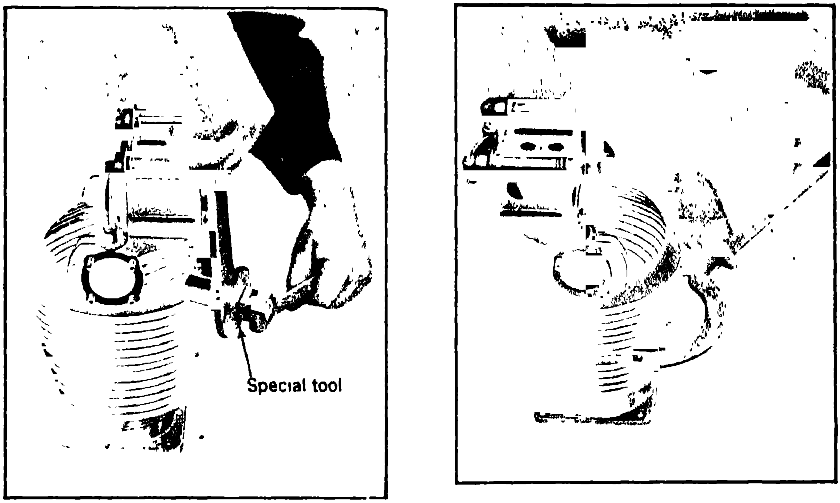


Fig. 533.—A Shows Method of Removing Sparkplug Bushings. B—Special Wrench for Unscrewing Cylinder Head Locking Ring.

The slow-running jet is also marked on the top of the slow-running device 4. Generally the air jet g or atomizer is already correctly inserted on the test bench. It may occasionally be necessary to exchange the air- and fuel-jets. The latter depends upon the mode of fixing the suction pipe in the plane and is largely based upon the brand of fuel employed. Additional air jets also require larger fuel jets. Smaller air jets are apt to throttle the maximum performance of the engine, on the other hand, though, they ensure an elastic and unsensitive operation of the engine as well as a good acceleration from slow running to full-open throttle, particularly during the cold season.

See that the air drawn in the carburetor is well heated at low temperatures as well as with a slow-running engine. For gasoline and benzol mixture the temperature of the inspired primary air should amount to about 25 degrees to 30 degrees Centigrade. A special chamber provided on the exhaust collector which is supplied on special order serves for a preliminary heating. In general, the maximum power of the engine is considerably increased when the engine is hot, as soon as cold air is drawn in at full load On the other hand, though, especially in the slow-running position, the temperature of the air should be as high as possible. For this reason a

shutter has been built into the warm air supply piping for the temperature control.

The compensating jet governs the amount of fuel for each fuel jet combination. The compensating jet should be as large as possible. The most favorable compensating jet is easily found by testing the maximum performance of the engine with different sizes of jets. In the first mixing stage, the air drawn in atomizes the fuel leaving the fuel jet. Hence, a preliminary carburetion of the fuel already takes place in the nozzle stem.

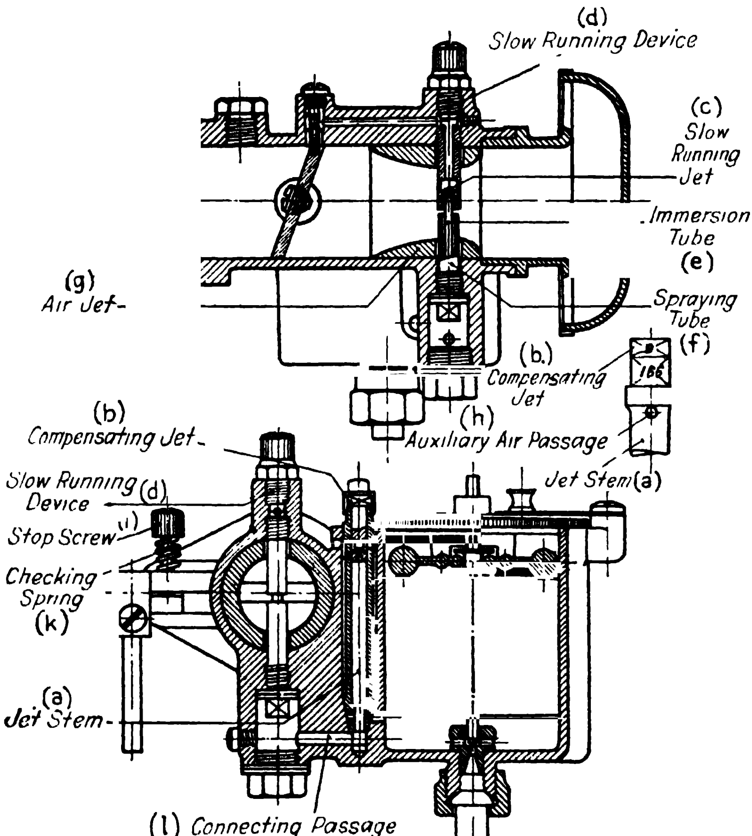


Fig. 534.—Sectional Drawing Showing Construction of the SUM Carburetor Used with Siemens-Halske Aviation Engines.

The slow-running jet together with the ascension tube may be considered a small carburetor serving the purpose of starting the engine and attaining a low speed of revolution. To start the engine the throttle valve should be set to slow-running (nearly closed entirely). The slow-running jet must be large enough to enable an easy starting of the engine in a warm

condition and to avoid its stopping. Fix speed of 300 to 500 r.p.m. at the throttle valve with the aid of the stop screw. Do not interfere with the jets supplied and to not try to widen the apertures. To decrease the fuel supply of the fuel jet during operation a pipe with cock may be connected to the jet channel (Sum Quality Governor). This arrangement enables a further access of any quantity of air into the jet passage beside the fixed quantity of compensating air and thus saves fuel. The quality governor should be closed for obtaining the maximum power of the engine. These governors are only supplied on special order and they are only of special value for altitude flights and consumption competitions.

QUESTIONS FOR REVIEW

1. What are the main features of the Siemens-Halske air-cooled engines?
2. What are the main points to have in mind when fitting the engine in the fuselage?
3. Describe advantages of exhaust collector and preheating device.
4. Why is a two piece crankshaft used in Siemens-Halske engines?
5. What type of bearings is used and why?
6. Describe Siemens-Halske cylinder construction.
7. How are Siemens-Halske engines lubricated?
8. Outline steps in starting Siemens-Halske engines.
9. Name important steps in dismantling Siemens engines.
10. How are crankshaft main bearings removed?
11. Describe steps in dismantling crank case.
12. What precautions are necessary in reassembling the engines?
13. How are magnetos timed?
14. Outline principal Siemens-Halske ignition troubles and remedies.
15. What are the principal carburetion troubles?

CHAPTER XXXII

THE FAIRCHILD-CAMINEZ ENGINE

Main Features—Main Shaft Distinctive—General Description "Cam" Engine—How Low Propeller Speeds are Obtained—Drive and Valve Cams—"Cam" Engine Has Good Performance—Fairchild-Caminez Lubricating System—Oil Recommendations—Lubricating the Engine—Oil Pressure—Adjustment of Oil Pressure —Preparatory to Starting—Starting the Engine—Flight Operation—Periodic Inspection—Top Overhaul—Inspection of Piston Rings—Inspection of Valve Gear Assembly—Assembly after Top Overhaul—Complete Overhaul of the Engine—Inspection and Repair—Cam Rollers—Pin and Link Holder Assembly—Valve Cam and Drive Cam—Assembly after Complete Overhaul—Assembling Pistons and Rollers—Assembling Pistons and Links—Assembling Magneto Bracket—Timing the Engine—Oil Pump—Intake Manifold—Carburetor Specifications—Service Operation—Carburetor Settings.

Main Features.—The Model 447B engine is a four-cylinder radial engine of the reciprocating piston type operating on the four-stroke cycle. The engine employs the Fairchild-Caminez drive cam mechanism in which reciprocating motion of the pistons is converted into rotary motion of the propeller shaft by means of rollers in the piston operating on a double lobed cam. The mechanism is such that each piston completes four strokes per revolution of the propeller shaft. With the four stroke cycle that is used, each piston, therefore, completes a power stroke every revolution of the shaft. It is due to this that a high power output is obtained per cubic inch of piston displacement at a low propeller speed, the shaft speed in this engine being one-half that of a crank engine of equal piston displacement for the same power output. Another important difference of this cam engine from the usual crank engine is that the motion of the pistons in opposite cylinders of the cam engine is identical with respect to the engine axis, so that the piston inertia forces balance each other. Perfect running balance is, thereby, obtained without the use of counterweights, the cam engine being the only radial or four-cylinder engine in perfect inertia balance.

Main Shaft Distinctive.—In the Fairchild-Caminez engine, the four cylinders are arranged radially about a central rotatable cam as shown in Figs. 535 and 536. This cam is of the double lobed type, shaped generally like a figure 8. A roller bearing is mounted in each piston, the outer race of which acts directly upon this drive cam. Adjacent pistons are connected by a system of links, the contour of the drive cam being so designed that these links maintain the piston rollers in continual contact with the cam.

The main shaft of the engine is a straight alloy steel shaft to which the drive cam is splined. This shaft is supported in the engine case at the rear end by a roller bearing. The front main shaft bearing is a deep groove radial ball bearing which takes all the thrust load on the shaft and part of the axial load. The center plain bearing on this shaft is fitted with large clearance so that it takes but little of the axial load and acts mainly as a

means of transmitting the lubricating oil from the case to the shaft, from where it is distributed throughout the engine.

The main engine casing consists of two aluminum alloy castings which are bolted together at the plane through the cylinder axis, eight long studs being employed to hold the casing together. The front, or propeller end casting holds the valve cam followers. The engine auxiliaries, which consist of two magnetos, pressure and scavenging oil pumps, and tachometer drive, are contained in a separate casting that bolts to the rear main engine

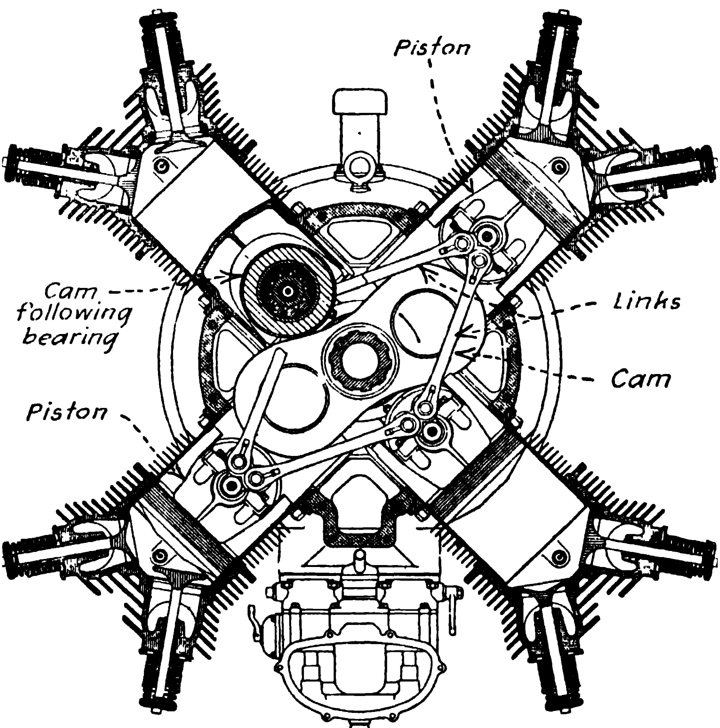


Fig. 535.—Plan Sectional Drawing of Caminez Engine that Uses a Figure Eight Profile Cam Instead of Crankshaft for Operating Pistons and Receiving Power Impulses.

casing. The engine is mounted in the airplane by means of the rear flange on the engine casing, provisions being made for eight ⅜-inch diameter bolts. The diameter of this mounting flange is twenty inches and the accessories behind this flange are so arranged that no connection on the engine need be disturbed when installing or removing the engine from the airplane. The external views of the engine, shown at Fig. 537, show the simplicity of the assembly and the substantial construction of the parts very clearly. Complete instructions for installing will be found in special chapter on engine installation.

With four strokes per revolution, the motion of the pistons in opposite cylinders in the cam engine is identical with respect to the engine axis. This produces complete inertia balance and results in smooth-running characteristics with a four-cylinder radial engine. By having the piston operate directly on the drive cam and avoiding the long connecting rod length necessary in the conventional radial engine, a more compact arrangement is secured, making possible sturdier construction, smaller size, and lower head resistance. The cam type radial engine further differs in that it provides an individual bearing to transmit power from each cylinder and thereby overcomes the objection to the conventional radial engine of having one connecting rod bearing taking the entire load of the forces acting in all cylinders.

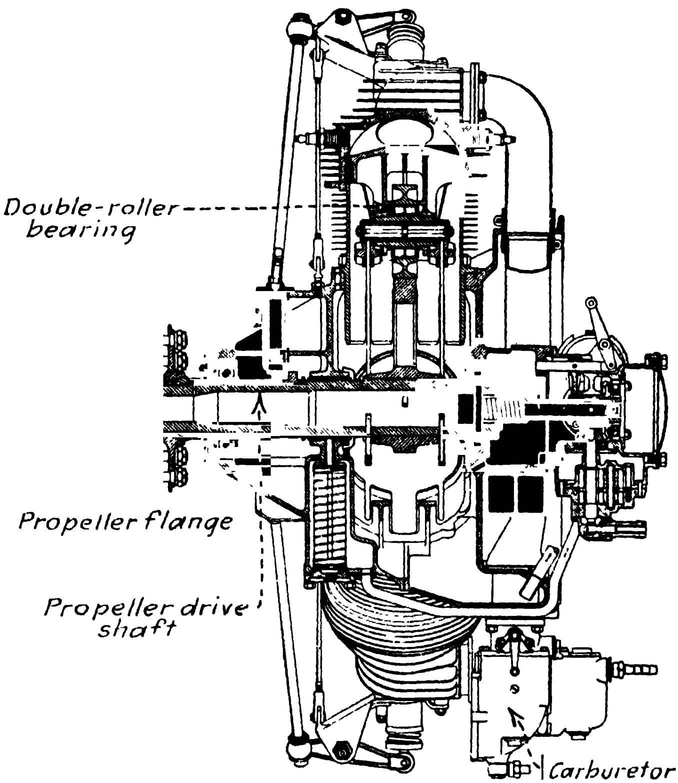


Fig. 536.—Side Sectional Elevation Drawing of Caminez Engine Showing Simplicity of Valve Gear and Piston Arrangement.

General Description "Cam" Engine.—Four openings are provided in the engine casing which receive the various cylinders. These cylinders, one of which is shown in part section at Fig. 538, consist of hardened steel finned barrels which are screwed and shrunk in special aluminum alloy heads.

Bronze inserts are shrunk in the heads for valve seats. Phosphor bronze valve guides are used. The tulip shaped exhaust valve is $2\frac{1}{4}$ inches diameter, and the mushroom inlet valve is $2\frac{1}{2}$ inches diameter; both valve lifts being $\frac{9}{16}$ inches. Pressed steel valve rocker brackets are bolted to the cylinder head at their rear end and attached to the engine case at the front end by a long rod, the construction being such that a firm support for these brackets is obtained without putting too much of the push rod load on the cylinder head casting. The valve rockers are alloy steel drop forgings and have hardened steel rollers which contact on the valve stems. The push rod ball ends are contained in grease tight adjustable screws in the rocker levers, the screws providing means for obtaining proper valve tappet clearances.

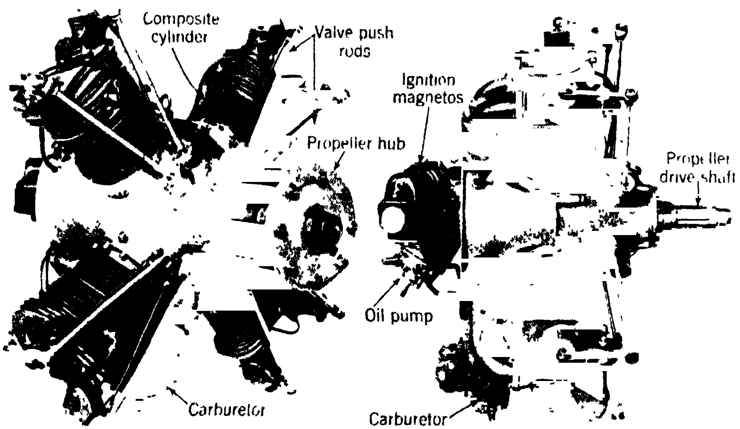


Fig. 537.—The View at A is the Fairchild-Caminez Engine Viewed from the Propeller End. Side View at B Shows Compactness and Simplicity of Assembly.

Provisions are made to lubricate the push rod ball ends through Alemite connections in the rocker pivot bearings. Since each piston makes four strokes per revolution in the engine, single lobed intake and exhaust cams are mounted directly on the main engine shaft which operates all the valves in the engine. The valve tappet plungers are contained in removable aluminum alloy guides which fit in the nose end of the main engine casing. Rollers are mounted on floating hardened steel pins in the end of the tappet plungers which contact with the valve cams. Small holes drilled through the main engine shaft throw jets of oil on these tappet plunger rollers for lubrication.

The pistons, as illustrated at Figs. 539 and 540, are made of heat treated aluminum alloy and are provided with four narrow compression rings. The pistons are of the slipper type with large bearing areas on their thrust sides Deep ribs are provided to strengthen the pistons and improve piston cooling. Special double row roller bearings are mounted in each piston, the

piston being made with detachable caps to facilitate assembly. A piston pin passes through the hub of these roller bearings at the ends of which link holders are fastened. The links inter-connecting the pistons, consist of alloy steel straps. They have hardened steel pins keyed at their ends which work in bronze bushings in the piston link holders. Ample bearing area is provided for these pins to reduce the unit bearing loads in the bushings. Lubrication of these bearings is obtained by oil jets in the main engine shaft which register with these bearings at every bottom stroke of the piston. The loads on these links and link pin bushings are due to the

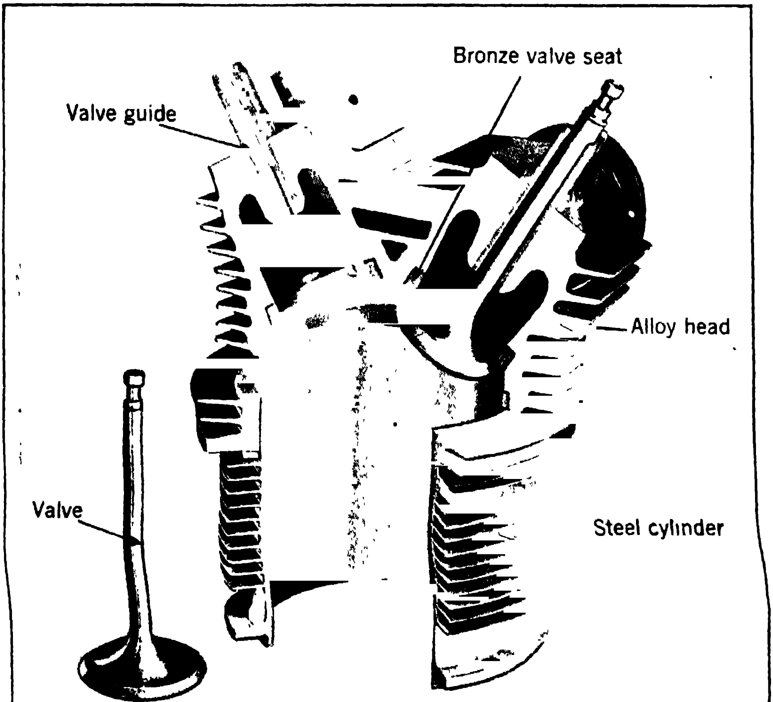


Fig. 538.—Cross Section of Fairchild-Caminez Cylinder Showing Steel Barrel and Aluminum Head Construction, Valveports and Valves.

inertia force of the piston assembly away from the cam. The cam shown at Fig. 541 is so shaped that there is a practically constant load on these links at any given engine speed.

The four-cylinder X arrangement lends itself admirably to air cooling. Moreover, the cam mechanism allows a more compact arrangement of cylinders, so that the overall diameter is considerably less than that of the conventional radial of equal power output. This small overall diameter, together with the wide gap between adjacent cylinders results in a small projected frontal area and allows good visibility. The excellent streamline shape of the main engine case and the absence of engine accessories projecting into the streamline, also reduces the head resistance. The installation

of this engine requires no engine cowling and tests have shown that the engine will cool satisfactorily at full throttle in a 30 mile air blast.

How Low Propeller Speeds are Obtained.—By providing four piston strokes per revolution instead of two, as in the crankshaft engine, the cam type engine obtains high power output per unit of displacement without resorting to high propeller speeds. The cam engine thereby obtains the effect of a two to one propeller reduction gear without the increased cost, complication, and added weight of this gearing. With the cam mechanism four cylinders are arranged radially about the central cam. Each piston is provided with a large roller, mounted on the piston pin, which contacts with this cam. A link arrangement is used to connect adjacent pistons,

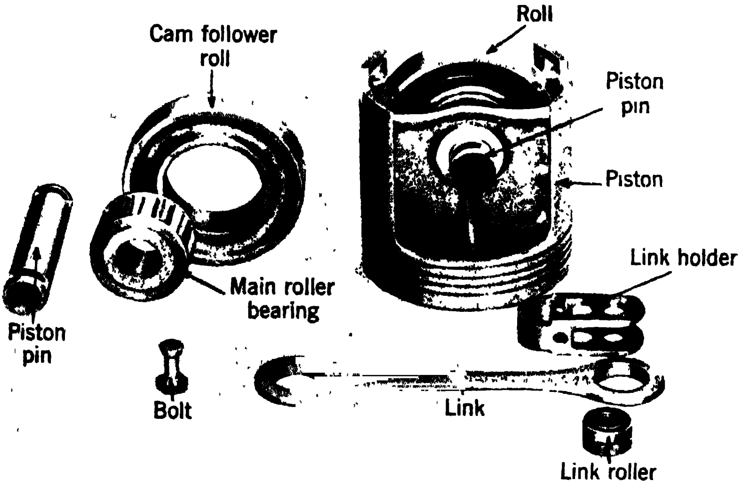


Fig. 539.—Piston and Roller Assembly and Details of Piston Roller Bearing, Link and Link Holder Parts of Caminez Engine.

and the shape of the cam is such that the piston rollers are constrained to follow the outline of the cam by means of the links provided. The drive cam is mounted directly on the engine propeller shaft and the four cylinders are set at right angles to each other about the central axis and act as guides for the reciprocating pistons. At each end of the piston pin is an intermediate link holder to which the piston connecting links are attached. The use of intermediate link holders which are free to pivot about the piston pin axis equalizes the tension in the piston connecting links and compensates for cylinder misalignment or any inaccuracy of the cam. The intermediate link holders prevent any piston side thrust being set up by forces acting in the links and provide an automatic compensation for the clearance between the cam and piston rollers. All engines are assembled with clearance between roller and cam not exceeding $\frac{1}{64}$ of an inch. Tests on the Model 447 engine have shown that the engine will operate satisfactorily

with $\frac{1}{16}$-inch clearance, although careful measurement after long tests indicate no increase in initial clearance between the cam and rollers.

The motion of the piston due to the drive cam is similar to that which would be obtained with a crankshaft in which the crank angle is equal to twice the angle of cam rotation. Referring to the diagrammatic illustration at Fig. 542, position 1 shows piston in cylinder A at top dead center. In position 2, this piston has moved down while the cam rotated 45 degrees. The force F_1 acting in the cylinder produces a force of F_2 on the drive cam which acts with an equivalent moment arm equal to the distance d, the magnitude of the turning moment being $F_2 \times d$. Position 3 shows the cam

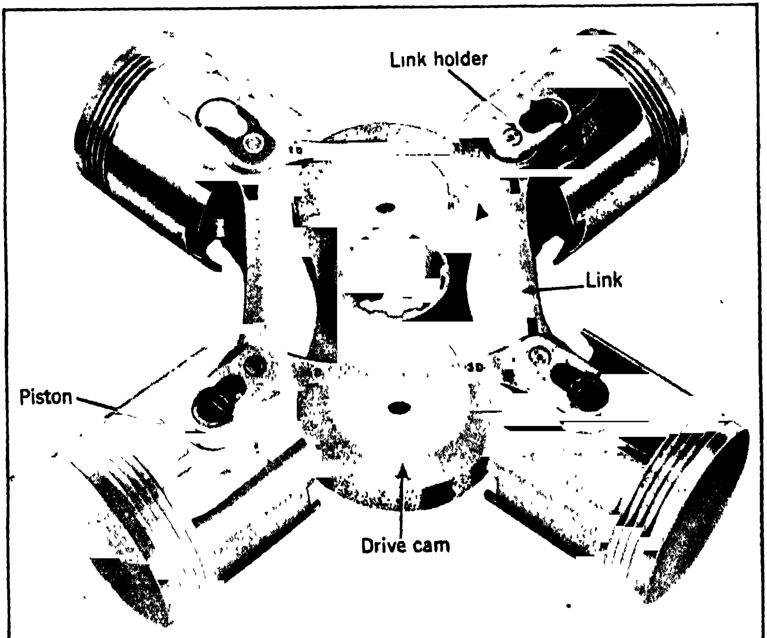


Fig. 540.—Piston, Roller Bearing and Link Assembly, Showing Arrangement About the Drive Cam in Caminez Engine.

at 90 degrees rotation with piston in cylinder A at the bottom of its travel. The piston in each cylinder has completed a full stroke while the cam made one-quarter of a revolution. The piston in cylinder A has completed a power stroke, piston B a compression stroke, piston C an intake stroke, and piston D an exhaust stroke, one engine cycle having been completed in 90 degrees of rotation.

This engine is unconventional in the method of converting reciprocating motion of the pistons to rotary motion of the drive shaft. The engine has been thoroughly ground and air tested and other designs of greater horsepower are also in progress. The cylinders are 5⅝ inch bore and 4½ inch stroke and the engine weighs 360 pounds complete with all accessories except starter. Its rating is 150 horsepower.

Drive and Valve Cams.—The drive cam is a chrome vanadium forging, heat treated to obtain maximum surface-hardness on the cam profile, and carefully ground to conform to a master cam which has been generated to be correct to within .002 inch. This cam is splined to the main engine shaft as shown at Fig. 541. The piston rollers are special double-row roller bearings, the outer races of which act as the cam rollers while the inner race of the bearing is mounted on the piston pin. The roller races are made of high chrome, high carbon steel and are finished by grinding and lapping. Twenty $\frac{9}{16}$-inch rollers, contained in an extruded bronze cage, are used in each bearing as shown at Fig. 539.

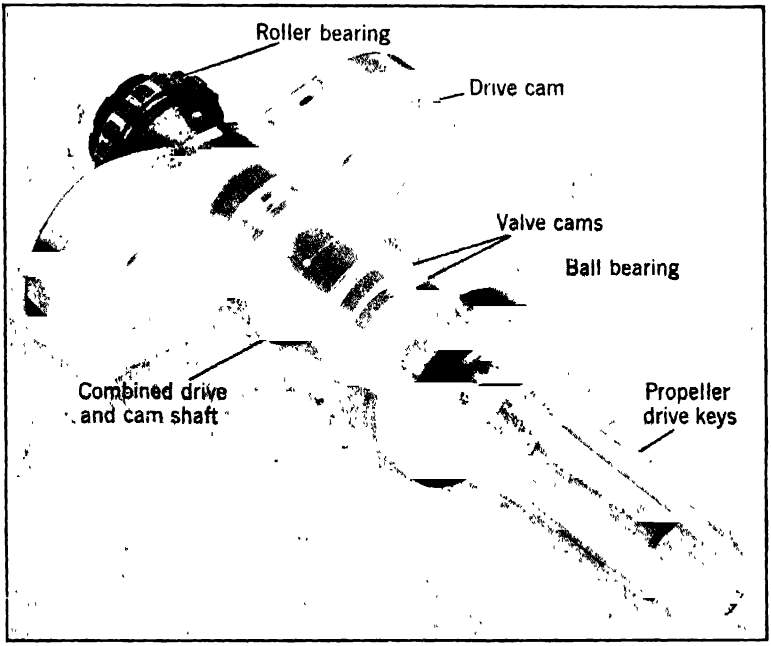


Fig. 541.—Engine Driveshaft Assembly with Main Drive Cam, Valve Operating Cams, Main Roller Bearing and Ball Thrust Bearing.

One intake and one exhaust valve cam are formed on an integral sleeve which is keyed on the main engine shaft. These cams operate all the valves in the engine. Since each piston makes four strokes during each revolution of the drive shaft, this shaft rotates at the correct speed to operate the valves. The single lobe on the valve cam opens each valve during one revolution of the engine. The firing order of the engine is 1-2-3-4. The valve tappet plungers are contained in removable aluminum alloy guides which fit in the nose end of the main engine case. Hardened steel rollers are provided in the end of each tappet plunger to contact with the valve cam. A small hole is drilled through the main engine shaft which supplies oil to a series of holes in the valve cam to lubricate the tappet rollers and guides.

"Cam" Engine Has Good Performance.—The first production Cam engine was installed in a Waco Ten three-place airplane manufactured by the Advance Aircraft Company of Troy, Ohio. The illustration in the chapter on engine installation shows the simplicity of the mount and the clean installation of the Cam engine. The Waco Ten is a standard commercial airplane which is regularly supplied with the OX5 engine. The Cam engine in this airplane results in a lighter installation and a 50 per cent increase in power. Its small frontal area permits the mounting of the Cam engine

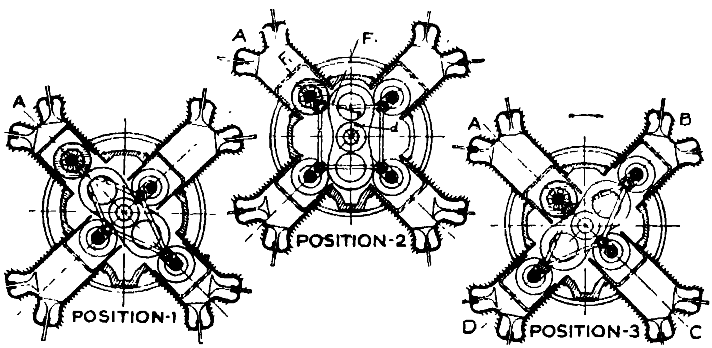


Fig. 542.—Diagram Showing Cam Mechanism in Three Positions During One Piston Stroke.

higher in the airplane without affecting visibility. The higher thrust line of the propeller, due to the raised engine mount, has resulted in satisfactory flying characteristics in this airplane. The 50 per cent increase in engine power over the OX5, as well as the greater efficiency of the low-speed propeller, has given the Cam engine airplane a considerably improved performance over the usual engine installation. With the Cam engine the Waco takes off in three to four seconds in a very short run. The ship has a greatly increased high speed and almost double the ceiling of the OX5 engined airplane. Despite the increased reserve power of the Cam engine, its fuel consumption at cruising speed is 30 per cent less than the OX5 airplane. A greater cruising radius results with the same fuel capacity. The improved fuel consumption of the Cam engine is accounted for by the greater efficiency of the engine combined with its lower head resistance, its lighter installed weight, and the higher efficiency of its low-speed propeller. Comparative flight tests were made between identical Cam engine and OX5 Wacos. With the OX5 turning 1,500 r.p.m. at full throttle, the Cam engine Waco maintained the same airplane speed when throttled to 820 r.p.m., at which speed the Cam engine was developing but half its full throttle horsepower. The OX5 at full throttle had consumed 9½ gallons per hour, while to maintain the same flying speed the Cam engine consumed 5½ gallons per hour.

To test the flying characteristics at altitude, the Cam engine with pilot, two passengers and full load of fuel, which produced a useful load of 750 pounds, climbed to 15,500 feet. In a test to determine the fuel consumption that can be obtained with the Cam engine, a seventeen hour twenty minute nonstop flight was made. The plane took off with a useful load of 1,001 pounds and during the flight consumed 85.44 gallons of gasoline which is an average consumption of 4.9 gallons per hour.

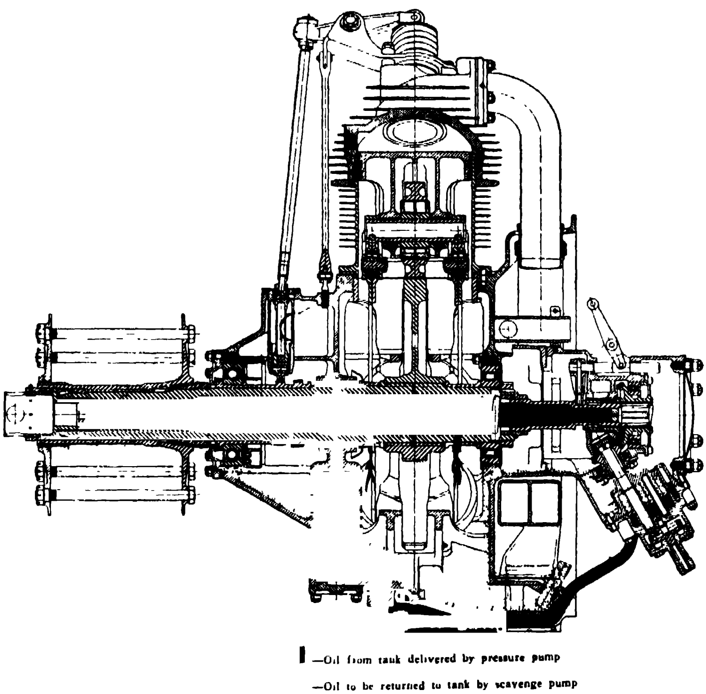


Fig. 543.—Sectional Diagram Showing Lubricating System of Fairchild-Caminez Engine.

Fairchild-Caminez Lubricating System.—Lubrication of the engine is accomplished by a pressure—dry sump system as shown at Fig. 543. The two gear type oil pumps are driven from the rear auxiliary shaft, and are mounted as a unit as shown at Fig. 544. The lower pump receives oil from the external tank and delivers it under pressure, through a line running under the case to the oil screen, which will bypass should it become clogged, and then to the oil transfer bearing. This bearing feeds the hollow main shaft, which serves to distribute oil to all bearing surfaces. Nozzles, placed radially in the mainshaft on each side of the driving cam, throw oil to pistons, piston rollers, piston links and cylinders. Drillings through the driving cam allow oil to pass to the surface of this cam, and radial drillings on

each side of the valve cams allow oil to pass to the valve cams, followers and tappets. Sectional drawings at Fig. 545 show the oil pump construction very clearly.

The two anti-friction bearings on the main shaft are lubricated by the oil mist created in the case by the moving parts. The auxiliary shaft at the rear of the engine is hollow, and is fed through a small hole in the plug at its forward end. Drillings in the auxiliary shaft supply oil to the magneto and oil pump drive gears, and to the bearing supporting the shaft. Surplus oil in the engine all returns to a sump in the lower part of the case, whence it is picked up by the upper scavenging oil pump and returned to the oil supply tank.

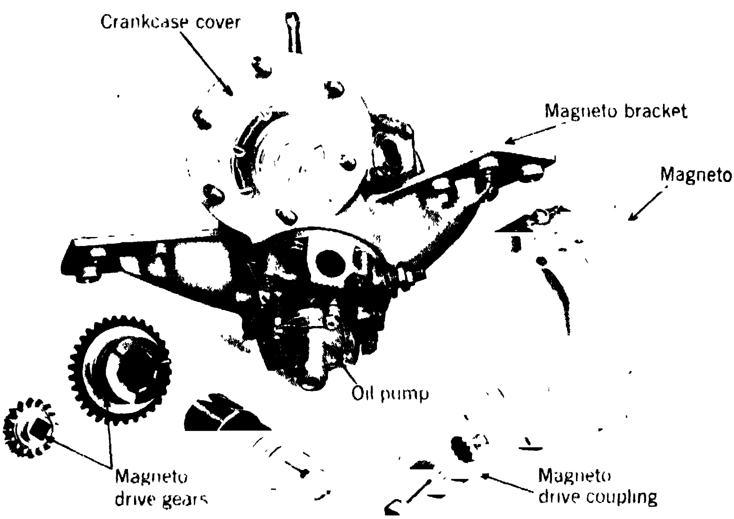


Fig. 544.—Magneto Bracket and Oil Pump Assembly of Caminez Engine Showing the Detail Parts and One of the Scintilla Magnetos.

It is quite as necessary to use the proper grade or body of oil as it is to use an oil of high quality. Design and operating conditions have a definite influence on the oil that is best suited to the engine. Oils that are too light will not give adequate protection to the cylinders and bearings, and may allow blow-by of the compressed gases above the pistons. Oils that are too heavy may in some cases cause excessive carbon and gumming and in extreme cold weather may not circulate properly. Oils that will maintain an adequate film when heated or when diluted with fuel, should be used. Oils that are too heavy, on the other hand, may cause an undesirable drag, causing power loss and abnormal fuel consumption. Aircraft engines all operate at heavy loads as has been fully considered—nearly the full power available from the engine is used most of the time. Hence, high temperatures are developed that are altogether different from those encountered in automobiles, which run at about 25 per cent throttle most of

the time. Air cooling also allows higher temperatures (with greater thermal efficiency) and the fact that the Cam engine is cooled largely by head wind, and not by propeller draft, due to the large propeller and small engine diameter, prevents it from running too cool. A lubricating system of positive action circulates heavy lubricants under nearly any condition thus supplying ample oil to the bearings. Although high compressions are used, detonation is minimized by pistons that are designed to quickly distribute the heat to the cylinder walls and yet stay hot enough to avoid tendencies toward carbon formation when the correct oil is used.

Oil Recommendations.—Summer above 32 degrees Fahrenheit, Gargoyle Mobiloil "D" or high grade oil of similar body and character, is recommended for Fairchild-Caminez engines when ground level temperatures are above freezing. Such an oil is heavy enough for all summer conditions.

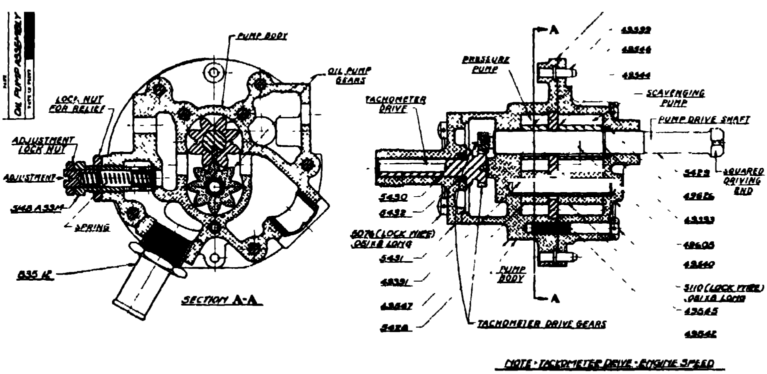


Fig. 545.—Sectional Drawing Showing Oil Pump Assembly of Caminez Engine.

Winter below 32 degrees Fahrenheit, Gargoyle Mobiloil "D" or similar high grade oil, is also recommended when ground level temperatures are below freezing, provided that the oil is heated before the engine is started. Should there be no facilities for preheating the oil, Gargoyle Mobiloil "B" or equivalent is recommended. This oil is more fluid at low temperatures and will provide immediate circulation. When ships are housed in warm hangars, special heating precautions are unnecessary.

When engines at rest are apt to be subjected to freezing temperatures for a few hours or longer, oil should be drained from the reservoir immediately on stopping the engine. This oil may be saved and stored in a warm place. Before starting the engine again the warm oil should be put back in the reservoir. If the oil becomes chilled and too sluggish, it should be warmed by placing the can near a fire or in a warm place for several hours. If that time is not available the cans of oil can be placed in boiling water. It is inadvisable to place the cans in direct flames, as the oil might become hot enough to decompose at one spot while the rest would be scarcely warm. Stirring, of course, speeds up the warming. Oil should not be

heated to more than 150 degrees Fahrenheit. When warm oil is poured into tank, pour ½ gallon through the back breather, to assure lubrication on starting.

Lubricating the Engine.—Before each flight, make sure that the oil tank is filled to the proper level. Sufficient space should be allowed for expansion and for oil already in the lines. At no time should the supply be allowed to fall below two gallons, as less than this amount will circulate too fast and will overheat. Should the oil supply be nearly used up on long flights, it is far safer to land and refill if the supply becomes low. The oil reservoir should be drained and refilled after every twenty hours of flying. This is best done just after a flight, when the oil is warm and stirred up, the latter condition helping to remove sediment that may be in the system. Under no circumstances should a flyer take a chance on using the oil for more than twenty hours, as the oil becomes contaminated with fuel, carbon and dust, which if allowed to accumulate, might cause damage to the engine. At engine overhaul periods, all oil lines and the oil tank should be thoroughly cleaned with kerosene.

Located forward of the cylinders, in the lower part of the case, is an oil screen which clears the oil of large particles. This screen is easily removable through a cover plate attached by four cap screws. It should be removed and cleaned when the oil reservoir is drained, or after every twenty hours of flying. Clean it in kerosene or gasoline and dry it in air or with a lintless cloth—not waste. Waste clogs the mesh and washes out in service. The filter location is clearly shown in Fig. 543.

Oil Pressure.—Normal oil pressure at full throttle should run from 30 to 45 pounds. When idling, with the engine warm, oil pressure should be three pounds or a little more. When the engine is cold, pressure will be somewhat higher, due to the cool thickened oil. **Note—These pressures are lower than those required for many other engines, but the Fairchild-Caminez engine operates best with pressures recommended. If pressure falls below twenty pounds at nearly full throttle, land and find out why.** Should the gauge fail to show the required pressure, check over the following points before adjusting the bypass valve which is shown in detail drawings of the pump at Fig. 545. 1. Use of the wrong grade of oil. (Follow recommendations in this book.) 2. Loose or broken oil piping or connections. (Tighten or replace piping or connections.) 3. Clogged oil strainer. (Remove and clean.) 4. Bypass valve not functioning. (Examine and clean or replace parts as necessary.) 5. Broken oil gauge. (Replace with a new gauge.)

Adjustment.—The pressure may be increased or lowered by adjusting the bypass valve on the oil pump assembly. To raise the pressure loosen lock nut and turn adjusting screw clockwise, and to decrease pressure, turn it counter clockwise. Be sure to tighten the lock nut. Oil temperature should never be allowed to run higher than 200 degrees Fahrenheit. If it does, a landing should be made as soon as possible to ascertain the cause. Overheated oil may cause damage to cylinders and pistons, and is most likely to be caused by an insufficient supply in the tank. Chronic high oil temperatures may be caused by improper location of the oil tank in the

airplane. To check this, see recommendations under "Oil Tank Installations" in special instructions for installing the Fairchild-Caminez engine as well as others in a chapter to follow. The valve rocker arm shafts are lubricated through a high pressure fitting on the end of each rocker shaft. The rocker arm is drilled so that the ball joint is also lubricated when the high pressure grease gun is applied to the fitting. A heavy gear oil, such as Gargoyle Mobiloil "C," should be used in the gun, and each fitting should be lubricated every flying day. The Scintilla magnetos, which are standard equipment, should be lubricated every twenty flying hours. Use a high grade engine oil, such as Gargoyle Mobiloil Arctic, and apply four drops to each rear oil duct, and fill the front ducts. When inspecting the engine, one of the most important details is the thorough checking of the oiling system, and particularly the external oil lines and connections. Pay particular attention to the hose to and from the oil tank, and the tubing connecting the pumps with the sump and the oil screen chamber.

Preparatory to Starting.—Before starting the engine the following operations should be performed: 1. See that there are four gallons of lubricating oil in the oil tank. **Note—During freezing weather the oil should be heated to 100 degrees Fahrenheit or 40 degrees Centigrade before filling the tank. At the end of each day's flying the oil should be drained from the oil tank and stored in a closed container for use on the next flight.** 2. Lubricate the valve gear with Zerk gun using Marfax No. 3, Mobiloil CC, or other high grade grease of equal lubricating qualities. Use a thin grease in winter. The valve gear should be greased each five hours of running. If longer running is contemplated, self-feeding grease cups should be installed. 3. Turn the engine two revolutions by hand to make sure everything is free. Have switch "OFF" while turning engine. 4. Inspect all controls, fuel and oil lines, instruments, etc., as is customary before flying. 5. Prime the engine. Two or three strokes of the primer are sufficient. Do not prime a hot engine as the mixture will be too rich to fire in the cylinder. Turn the engine backwards two or three revolutions if this condition occurs.

Starting the Engine.—With all preparations complete, start the engine as follows: 1. Engine Equipped with Hand Inertia Starter. Crank the starter, withdraw crank, throw on magneto switch, leaving throttle closed, pull starter handle and hold till engine starts. The inertia starter will turn engine over about ten revolutions. The engine will start normally on the first or second revolution. Run engine at 400 r.p.m. (800 r.p.m. on tachometer) after starting. 2. Engine Equipped with Hand Booster Starter. Retard the spark fully, leaving throttle closed, throw on magneto switch and crank till engine starts. Spark control should be set to retard point of ignition to T.D.C. of engine. 3. Engine Equipped with Electric Inertia Starter. With throttle closed, throw on magneto switch. Press starter button to count of four, pull starter handle and hold till engine starts. 4. Emergency Hand Starting. For emergency starting by hand cranking, retard the spark, turn engine over twice and use the customary "OFF CONTACT" signals for throwing the magneto switch.

When the engine starts, run it at about 400 r.p.m. (800 r.p.m. on tachometer) for two or three minutes at which time it should be firing regularly.

Open the throttle steadily to full throttle, holding the engine at maximum speed for only a moment to note the r.p.m., then close the throttle steadily to idling speeds. The maximum speed on the ground should be between 890-950 r.p.m. (1,780-1,900 r.p.m. on tachometer) depending on the propeller used.

Do not run the engine on the ground at full throttle for more than a few seconds. The air stream with the plane at rest is small and cooling inadequate for full throttle operation and there is danger of damaging the engine.

The lubricating oil pressure at 850 r.p.m. (1,750 r.p.m. on tachometer) should be about 30 pounds with oil at 120 degrees Fahrenheit. If the engine sounds ragged at full throttle, after it is warmed up, retard the spark, run the engine at 450-500 r.p.m. (900-1,000 r.p m. on tachometer) and test each magneto by the bulkhead or instrument board switch. A missing engine is usually corrected by changing plugs. New sparkplugs should always be tightened after the initial warming and ground test to take up looseness from expansion and from compression of new plug gaskets.

Flight Operation.—The propellers used usually hold the engine to a maximum speed of 1,000 r.p m. (2,000 r.p.m. on the tachometer) in level flight at which speed it develops about 135 brake horsepower. In commercial flying the engine is usually throttled to three-quarter speed (775-850 r.p.m.)—(1,500-1,700 r.p.m. on the tachometer) at which speeds the engine develops about 65-85 brake horsepower.

The lubricating oil pressure should be set at 30 pounds when the engine is turning 850 r.p.m. (1,750 r.p.m. on the tachometer) and at ten pounds when the engine is idling at 250-275 r.p.m. (500-550 r.p.m. on tachometer) with oil temperature at 120 degrees Fahrenheit.

To set the pressure run the engine to warm the oil or heat the oil to 120 degrees Fahrenheit. Set the idling pressure at ten pounds first by cracking the relief valve cage off its seat until the pressure drops to the required point. Tighten the cage lock nut. Speed the engine up to 850 r.p.m. (1,700 r.p.m. on the tachometer) and with a screwdriver turn adjusting screw until the pressure stays at 30 pounds. Screwing in increases the pressure. Tighten the adjusting screw lock nut.

The carburetor is equipped with No. 36 main fuel jets for general service. With this combination of fuel and air jets the mixture gives good economy at cruising speeds, and is rich for power at full throttle. When cruising at part throttle the altitude adjustment may be used to thin the mixture for good economy. When climbing at full throttle, the mixture should be full rich, as the air blast on the engine is low and the engine runs cooler with a rich mixture.

Periodic Inspection.—All external working parts of the engine are accessible for inspection and repair. 1. Rotate the engine by the propeller. Have switch "OFF." The compression in each cylinder should be strong. There should be no other hard points of turning other than the four compression points. 2. Inspect the ignition wires to see that terminals are on plugs and that wires are not chafing. Clean the porcelain of each plug to prevent short circuiting from dirt. 3. Inspect, grease and oil valve gear. (See Fig. 546.) 4. Adjust tappet clearance to .008 inch when engine is cold.

5. Oil magnetos every 25 hours flying. 6. Clean oil and gasoline strainers. 7. Check magneto breaker point clearance with gauge in tool kit, and clean points.

All work on the engine should be precision work. The engine, if run correctly, will give unusually long service before even a "top overhaul" is

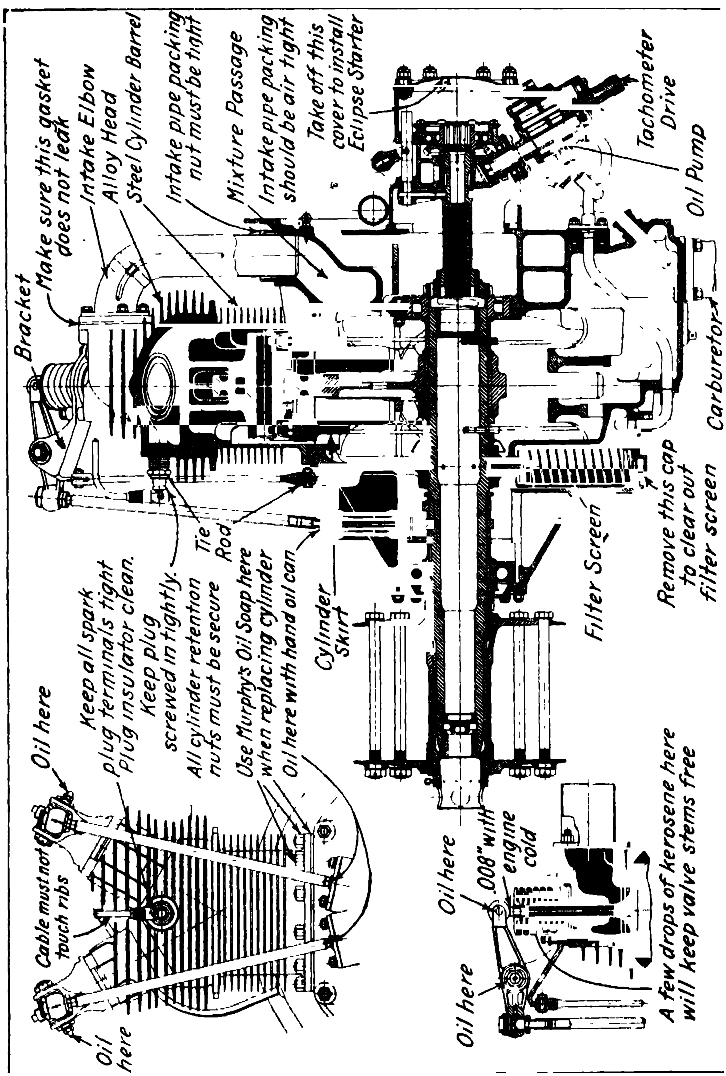


Fig. 546.—Longitudinal Sectional View of Fairchild-Caminez Engine Sho mporti Pa nd ing Attention During Inspection or Overhauling ss.

necessary. A general overhaul will not be necessary unless some part goes radically wrong inside the cam case. Usually this can be repaired without parting the cam case or pulling the shaft. Owners of "Cam" engines may send their engines to the factory for overhaul and reconditioning. This

work is done at a nominal sum. Complete overhaul kits may be purchased which include all the tools necessary for complete overhaul.

Top Overhaul.—A top overhaul is necessary only when the engine is losing power from poor compression or is detonating from carbon deposits. The procedure of disassembly for top overhaul is as follows: 1. Take out all sparkplugs. 2. Remove all valve rocker brackets, pushrods, rockers and tie rods in a unit. Disconnect the tie rod at the camcase end. Remove the three nuts holding the bracket and lift the assembly off intact. 3. Take off exhaust manifold. 4. Take off intake elbows. Unscrew packing gland nut two or three turns to loosen packing. Intake elbow will slip out. 5.

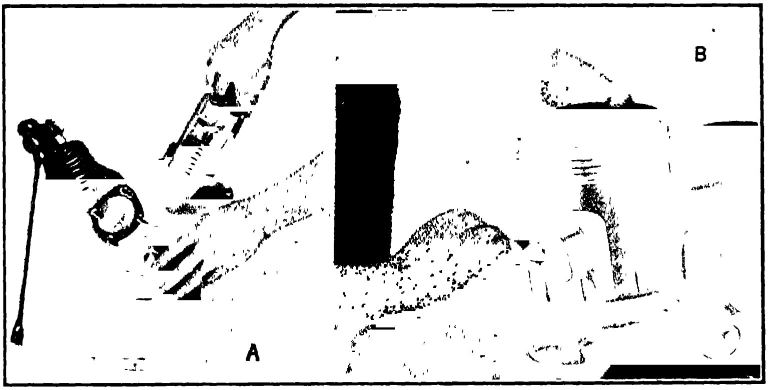


Fig. 547.—Method of Compressing Valve Spring to Remove Valve Collar Retainer Shown at A. How to Pull Link Holders Outlined at B.

Remove all ignition wires from the cylinder clips. 6. Remove cylinder flange nuts and pull off the cylinders.

Caution: Do not use a chisel between the cylinder flange and skirt flange to start the cylinder. Tap the top of the cylinder sidewise with a rawhide mallet or tap the exhaust of inlet port flange which will break the joint loose and allow the cylinder to be easily pulled off. Never use hard hammer for this purpose. Be careful that the piston does not fall and hit the studs as the cylinder is pulled off. Cut sixteen pieces of 3/8-inch rubber gasoline hose about two inches long and slip a length over each of the four cylinder studs near the center plane of the cylinders. These will prevent the pistons from being nicked when the cylinders have been removed. Do not remove the pistons unless inspection of the cam rollers and links require more than a top overhaul.

Compress the valve springs with the spring tool as shown in Fig. 547 A, and remove the spring collar keys. The springs will slip off the valve stem with the compressing tool. Remove the ringlets from the valve stems and withdraw the valves.

For rough grinding the valves use Clover Grinding Compound Grade "C" or "B." Finish grinding with Grade "A." Pits will usually appear only on the aluminum bronze valve seat and seldom on the valve. Grind only

sufficiently to gain a continuous seat. It is not necessary to grind until all the deep pits have disappeared as too much grinding will wear away the seat unnecessarily. Assemble the valves in the cylinders and test for tightness by filling the gas passages above the valves with high test gasoline. Wetness around the valve in the combustion-chamber indicates a poor seat and the valve should be ground until the test shows it to be tight.

Inspection of Piston Rings.—If the lubricating oil consumption has been normal previous to the top overhaul and the rings are in good condition, it is advisable not to disturb them. If the rings are worn so that the gaps are too large they should be replaced with new rings. See Fig. 548 for clearances in fitting the rings. It is very essential that these clearances be adhered to. When fitting in new rings, stagger the gaps 180 degrees. The oil regulating ring should be inserted with the cutaway edge at the bottom of the ring groove. The carbon should be scraped from the piston head and cylinder head with a blunt or dull scraper. A sharp tool will cut the aluminum.

Inspection of Valve Gear Assembly.—If the rocker arms have been thoroughly greased with the recommended greases after each five hours flying, there should be very little wear in any of the valve gear parts. Try the valve rocker bushings for excessive play due to wear when new. These bushings are given .002-inch clearance. Replace these bushings with new ones if wear becomes greater than .004 inch. When assembling the valve rocker arm and bracket assembly the pin nuts should be pulled up tight so that the hardened steel sleeve is held tight between the steel bracket bushings. There should be at least .004 inch end clearance between the bracket bushings and the bronze rocker bushings. A smaller clearance will not allow sufficient space for a good film of grease. (See Fig. 549.)

Assembly after Top Overhaul.—After the overhaul is completed proceed with the assembly in the following order: 1. Assemble valves and valve springs in cylinders. 2. Assemble valve gear assembly, i.e., rocker arm, roller, push rod, tie rod and bracket. 3. Secure valve gear assembly as shown at Fig. 549 to cylinder head making sure that the spacers are in position on the two front studs. Each valve gear should be assembled to the same valve from which it was removed so that the tie rod will go back into place without adjusting the eye screw for the proper tension on the rod.

4. Slush the cylinder wall and piston rings freely with lubricating oil. Turn the driveshaft until the piston is on top center. Remove the rubber nipples from the studs. Squeeze the rings with the ring squeezer and slip the cylinder over the piston. Guide the push rod ends into their sockets as the cylinder is slid over the piston. When the rings are in the cylinder, remove the ring squeezer, then lower the cylinder into position. Take all necessary precautions to have the cylinder flange free from burrs or dirt. Cover the flange with Murphy's Oil Soap or similar sealing compound to assure an oil tight joint. Do not let the piston fall over onto the cylinder studs and get nicked. Use the ring squeezer in the repair kit and be sure the rings do not break or bind as they enter the cylinder.

5. The cylinder nuts should be started onto the studs before the cylinder is completely seated because the lowest fin will prevent the nut from going onto the screw if the cylinder is seated. Set down evenly on the cylinder

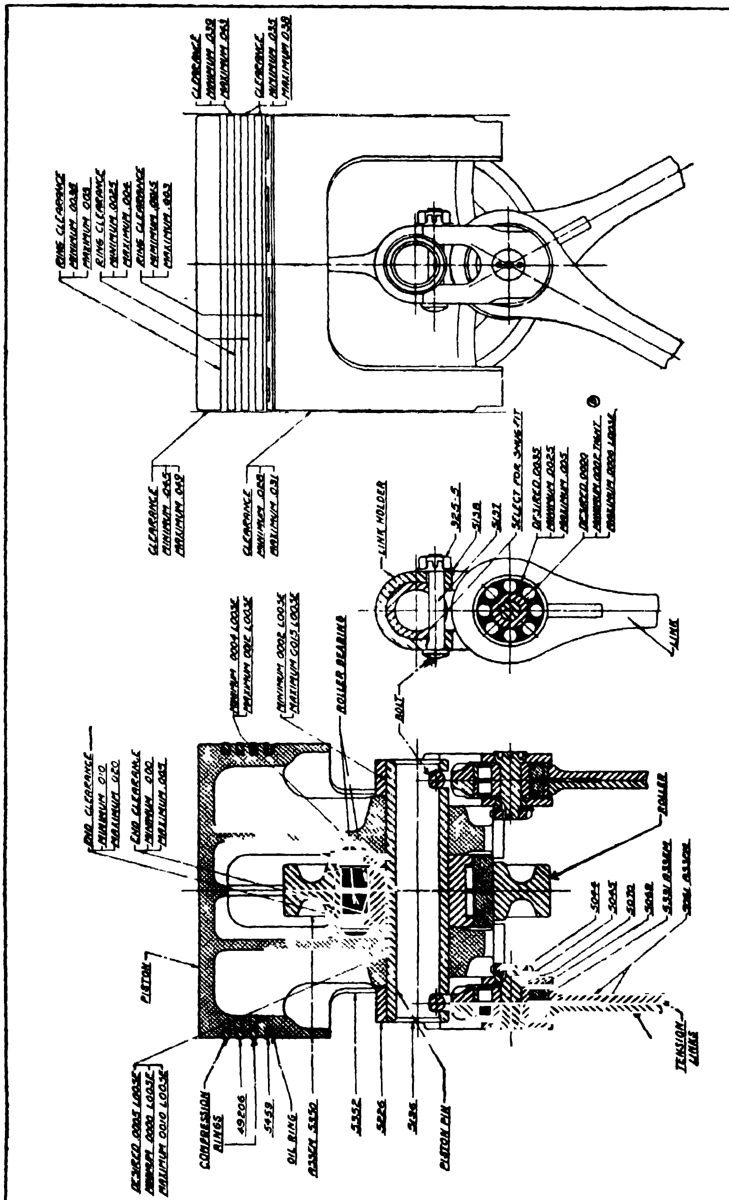


Fig. 548.—Drawing of Piston and Link Assembly of Fairchild-Caminez Engine Showing Clearances and Construction of Parts.

nuts and pull them all tight. 6. The packing in the intake manifold gland does not need replacing unless it has become hard or is damaged. If spares are not at hand cut 5/16 inch lengths of two inch inside diameter by 2¼ inch outside diameter rubber hose with cloth insertion which will serve well as packing for the gland. Tighten up on the gland with a light pull on the gland wrench. This construction is clearly shown at Fig. 546. 7. Screw up on the elbow flange nuts at the intake port making sure that the gasket is intact and that the flange seats evenly.

8. Connect the rocker bracket tie rod to the eye. The tie rod should be about 1/32 inch shorter than the distance from bracket to eye hole so that it is necessary to depress the front end of the bracket to slip in the bushing. This places the tie rod under an initial tension. Screw the nut of the clevis bolt tight and lock after assembly is completed. 9. Set the valve clearances by adjusting the nuts at the top of the push rods. Exhaust valve clearance cold—.008 inch; Inlet valve clearance cold—.008 inch.

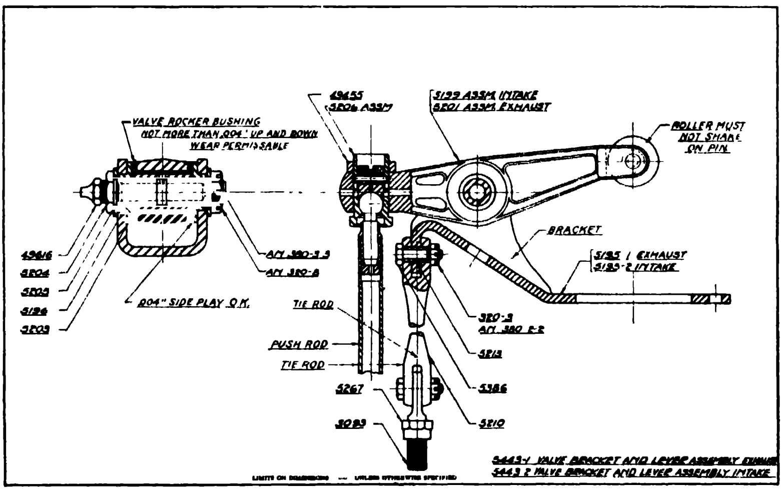


Fig. 549.—Valve Bracket and Lever Assembly of Fairchild-Caminez Engine.

10. Screw in the sparkplugs and connect the ignition wires. The sparkplug gap should be set at .015 inch to .020 inch. The threads of the plug should have no burrs on them. The threads of the sparkplug bushing are of duralumin and a burr on the plug threads will tear the threads in the bushing, making it necessary to insert a new bushing. 11. After a top overhaul the engine should be run at 500 r.p.m. (1,000 r.p.m. on tachometer) for an hour before flying This will allow the rings to reseat themselves before the engine is loaded and all other internal parts to be thoroughly oiled and properly seated on their co-acting members.

Complete Overhaul of Engine.—Disassembly: A special repair kit of tools is required to make a complete overhaul of the engine. 1. Remove cylinders as given in procedure for "Top Overhaul." 2. Remove Pistons. Straighten lip on washers and remove link holder bolts. Draw piston pins

with pin puller in repair kit or by inserting end of 3/8-inch open end wrench in slot at end of pin and twisting while pulling as in Fig. 547 B. Lift piston and roller off cam. Keep the respective pistons, rollers and pins matched as they are balanced against opposing pistons to 1/8 ounce. 3. Parting the Cam Case: Unscrew driveshaft nut and remove end plate. Pull the ball thrust bearing by using the special puller provided in the repair kit. The lugs in the puller ends are hooked into the outer ball race of the bearing. The strongback screw of the puller bears against the end of the shaft. Pull the valve cam using the same puller with lugs grappling the boss on the cam sleeve. Disconnect the oil pressure line from pump to cam case. Remove nuts from studs holding the two halves of the cam case. Tap the case with rawhide mallet to break the joint and loosen the cylinder skirts. Remove the four skirts. These are shown at Fig. 546.

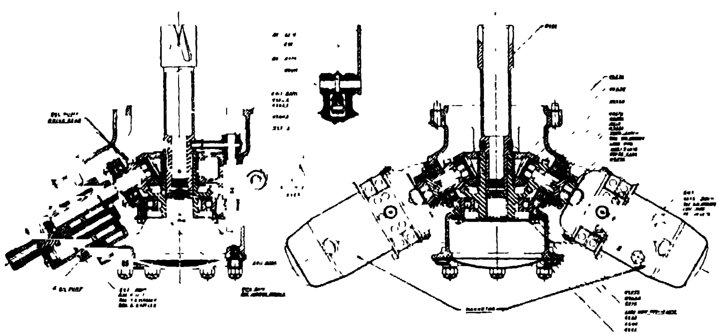


Fig. 550.—Magneto Bracket Assembly of Fairchild-Caminez Engine Showing Simplicity of Accessory Drive Mechanism.

Part the cam case, removing the front half over the end of the shaft. Draw the driveshaft with roller bearing out of the rear half of the case. The links and holders will hang on the shaft as it is withdrawn. Take off magneto bracket assembly intact. (See Fig. 550.) When removing the magneto brackets, take out the terminal blocks from the magnetos leaving the blocks and ignition wires intact. Plug the sockets of the terminal blocks with hard wooden blocks. **Note—The complete magneto bracket assembly can be inspected without disassembling and if left intact it can be replaced without disturbing the timing of the ignition.**

4. **Disassemble Magneto Bracket.**—If necessary to disassemble the magneto bracket, remove spark retard lever, pull out magneto advance shaft with yoke and pin. Remove magnetos with drive spindles. Remove gear cover plates and pull out drive gears with ball bearings. Take off lubricating oil pump and drive gear with ball bearing. Remove bearing retainer and pull out auxiliary drive shaft and ball bearing.

Inspection and Repair.—1. Inspect cylinder and valve gear assembly as given under "Top Overhaul." 2. Examine piston rings for wear. If

the rings are worn too thin or the gaps are too large they should be replaced with new rings. Piston ring practice is changing continually so the customers should wire or write the factory for new sets of rings when needed. When replacing rings, set the gaps so they will be at opposite sides and check the ring side clearance with thickness gauges. The clearances are shown in Fig. 548. The clearances given should be followed closely for best results.

3. **Cam Rollers.**—Remove the bronze cages and the rollers from the piston roller-bearings. Clean the cages and examine carefully for cracks. The cage should be replaced with a new one if the slightest crack is found. Examine the rollers and inner race of the bearing. A few small pits in the race are not injurious if the main surface is good. Examine the outer race or cam follower. The outer surface of the race which rolls on the main cam should be smooth and bright. If the lubricating oil system is allowed to become dirty and the oil collects hard particles small enough to get through the oil strainer, the surface of the roller may be slightly pitted. It is not necessary to stone these pits all out, but the roller surface should be stoned with the finest grade carborundum to take down the minute projections from the roller surface. The stoning should be done with a rolling motion in line with the curvature so that no flat spots will be left on the roller surface. The stoning should merely smooth off the minute high spots. If the pits in the roller surface are many and deep the roller should be put in a grinder and the surface ground down. Usually a cut of .0005 inch will take off the pits. In any case not more than .001 inch should be ground from the surface of the roller. This will decrease the roller diameter .002 inch. The same amount should be taken off from each roller. Grind with small cuts and with a soluble mineral oil solution. When the rollers are ground down the clearance between cam and rollers is increased and the engine is noisy in operation. If the rollers are in poor condition new rollers should be put in. In no case should the roller clearance be more than .015 inch. The clearance is measured when the cam is on top center and with the other three rollers bearing tight on the cam. In any case of doubt send the rollers to the factory for examination.

4. **Piston Pin.**—Examine the piston pin carefully to see whether it shows signs of working at the ends where the link holder bolts bear on it. The bolts should be tight in the slots of the pin to keep it from working. 5. Link and Pin Holder Assembly: Note carefully how the link assembly is marked and assembled before taking apart for inspection. Take apart and assemble one link holder bearing at a time and finish the assembly before starting on the next. The link holders in front of the cam are marked F1, F2, F3 and F4. Those behind the cam are marked R1, R2, R3 and R4. Examine the bronze cages of the link roller bearings for cracks. Replace any cracked cage with a new one. Make sure that the link screw is inserted in the right direction so that the nut will be on the cam side of the links when the engine is assembled.

6. **Camshaft Roller Bearing.**—Examine rollers and race to see that they are not pitted. Examine cage to see that it is intact. 7. Valve Cam and Drive Cam: The cam will give no trouble unless it receives severe abuse.

Stuck rollers or poor oil may scuff the surface of the main cam. Examine cam surfaces for batter marks. If the surface of the main cam is rough, stone it down with the finest grade carborundum stone using a rolling motion over the curvature of the cam so that the stone will not make flat spots on the cam. Stone off only the rough spots which rise above the cam surface. Slight pits below the surface will not affect the operation of the engine. If the cam has received bad batter marks, the cam should be replaced with a new one. The cam should be pressed off from the rear of the shaft. Withdraw the steel oil nozzle before pressing the cam off. When pressing a new cam on the shaft make sure that the four oil nozzles covered by the cam are seated. The cam is marked A-B on one side of each lobe. These letters face the rear of the shaft (toward the roller bearing). The oil holes in the cam must line up with the oil nozzles in the shaft. The cam should go on with a light press fit. If the fit is too tight the cam will crack at the small section. The cam will be in correct relation to the valve cam if the oil holes are in line.

8. **Lubricating Oil Strainer.**—Withdraw the strainer and inspect for holes in the screening. Recover with No. 40 mesh 3,380, bronze wire screen if it shows signs of deterioriation. 9. Lubricating Oil Pump: Disassemble the lubricating oil pump and inspect the gear teeth for wear and the gears for tightness on the shaft. See Fig. 545 which shows the oil pump construction very clearly. 10. Inspect and repair cylinders and valve gear as given under "Top Overhaul."

Assembly after Complete Overhaul.—1. Precautions: Have all parts absolutely clean. Work with clean tools. Make sure that burrs are cleaned from all joined surfaces so that the joints will be tight. Smear a thin film of "Murphy's Oil Soap" or its equivalent on all joints. This helps to make an oil tight joint. Never allow a stud to remain loose but put an oversize stud in its place. Use only nuts with good thread. Always use a rawhide hammer for pounding as rawhide does not nick the parts. Always match parts by the numbers stamped on them. Follow fits given on assembly drawings.

2. **Order of Assembly.**—Mount rear half of cam case on assembly stand. Main Roller Bearing: If the roller bearing has been removed from rear end of shaft, slide it on to shaft making sure that the skew pin is in place and that the spacer has been put on. Set up tight on the nut and lock it securely by bending the lips of the lock washer. Driveshaft: Place the link assembly with link holders marked "R" over the rear end of the shaft with link bolt nuts toward the cam. Flush the roller bearing with oil and insert the shaft with roller bearing into the roller race in the rear half of the cam case. Place the link assembly with link holders marked "F" over the front end of the shaft and with link bolt nuts toward the cam. The links marked A and B assembled on the link holders marked F1, F2, F3 and F4, and links marked C and D are assembled to link holders marked R1, R2, R3 and R4.

Cam Case.—Examine the bronze plain bearing and oil passages. Renew the bearing if badly scored. Make sure that the oil holes line up when putting in new bushing. Flush the bronze bearing with oil and slide the front half of the cam case over the shaft but do not set up on the cam case nuts.

Cylinder Skirts.—Insert the cylinder skirts, putting each skirt in its respective hole. It can go in one way only. Screw up tight on the cam case nuts. Smear the shaft end well with graphited grease and shove the valve cam sleeve onto the shaft. The cam end of the sleeve goes on first and the sleeve should be a snug but not tight fit on the shaft. If a new key is necessary give it about .002 inch top clearance but no side clearance in the slot of the cam. See Fig. 551, also assembly view of engine at Fig. 546. Place the shims on the studs at the front of the engine cam case. **(Note—There are no centering shims on some engines.)** The shims should be the same as those taken out when the engine was dismantled. They center the cam under the cylinders. If a new driveshaft or valve cam has been assembled it will be necessary to center the drive cam and determine the thickness of centering shims required. To center the cam use inside callipers or inside micrometers between the cam and the cylinder skirt on the diameter. Tap the shaft either way until the cam is .010 inch to .015 inch back of center.

Ball Thrust Bearing.—Insert the ball thrust bearing into the retainer and slide the assembly consisting of bearing, retainer and spacer over the shaft. Tap with rawhide mallet or brass rod until the spacer seats on the valve cam sleeve and the retainer seats on the cam case. Now put on the cam case end plate and tighten up on the nuts. Screw up tight on the drive shaft nut using special adjustable spanner. See Figs. 546 and 551. Check up on the centering of the cam. If the cam is too far forward or too far to the rear, remove or add shims from behind the ball thrust bearing retainer equal in thickness to the distance the cam is out from correct position, i.e., .010 inch to .015 inch back of center. Assemble the valve cam followers complete. Use new gaskets under the guide flange. Insert the eight follower guides in their respective places as shown at Fig. 546.

Assembling Pistons and Rollers.—The piston rings should have side and gap clearance as given in drawing Fig. 548. This should be carefully checked as insufficient clearances will cause the rings to bind in the grooves at high engine loads. The respective pistons, rollers and pins should be replaced in their original position. If any new parts are added to the assembly the complete assembly must be checked for weight and balanced against the diagonally opposite assembly. The assembly consisting of piston, rings, roller bearings and piston pin is balanced against the diagonally opposite assembly to within ⅛ ounce. Small discrepancies in weight are compensated by removing aluminum from the piston at a point not highly stressed such as the inner part of the skirt. Never grind on the roller or the cage. If larger discrepancies exist between an old and new assembly, a piece of tubing of the correct weight to balance may be pressed into the piston pin of the lighter assembly and located at the center of the pin. Weighing should be done on sensitive balances as ordinary scales will not weigh accurately enough.

Assembling Pistons and Links.—Place rubber nipples over the four cylinder studs at the side of the pistons to prevent nicking them. Starting with piston No. 1, draw link holders marked F1 and R1 up through the cylinder skirt so that they can be attached to the piston pin. Start the

piston pin through the forward link holder (F) with slots turned toward the cam. Turn the shaft so that the lobe of the cam is up on No. 1 top center. Set the piston with roller on the cam and shove the pin through. The link holder bolt goes through from left to right when standing on the same side of the piston as the link holder. It will not go through in the reverse direction because the flat on the bolt head will be in the wrong position to clear the skirt of the piston. Use new lock washers each time the bolt is re-assembled and bend the lip up tight against the nut. The bolts should be a snug fit and not loose in the hole, as a loose bolt will allow the link holder to turn on the pin and wear both bolt and link holder. Proceed similarly with piston No. 2, No. 3 and No. 4. When the assembly is complete, check it over to make sure that all lock washers and nuts are tight. Assemble the cylinders as given under "Top Overhaul."

Assembling Magneto Bracket.—The magneto bracket contains the only gears in the engine. Care should be taken when inserting ball bearings and gears that everything works freely and that the gears are in line. Loose or tight gear fits will make a noisy engine. Insert shims between the bearing race and the cover to decrease the clearance of gear teeth. See Fig. 550. When the assembly is complete it should turn smoothly without binding at any points. Never allow an assembly to go on the engine if there are spots that bind. Find the cause and remedy same. Leave the magnetos off until ready to time the engine. Insert the auxiliary driveshaft with the yoke and put on the spark retard lever. Insert the auxiliary drive shaft spring. Turn the shaft so that the "O" marks on the end of the shaft line up with the "O" mark on the end of the aluminum bushing in the end of the drive shaft, slide the bracket into place and bolt it onto the cam case.

Timing the Engine.—The ignition is the only mechanism to be timed as the valve events cannot be changed. The ignition should be timed with a dial graduated in degrees bolted to the propeller hub. If a dial is not available the setting can be made closely by measuring the advance on the rim of the propeller hub with a flexible scale. The procedure is as follows: 1. Find top center No. 1 cylinder. 2. Turn the engine eighteen degrees backward (clockwise when looking at the front). On the rim of the propeller hub **(Note—not on propeller)** this amounts to 1.57 inches or about $1\frac{37}{64}$ inches (since the timing is measured on the drive shaft which turns in the same relation to the pistons as the camshaft of a crank engine, 180 degrees on the drive shaft corresponds to 360 degrees on the cranks of a crank engine). 3. Set the opening of the magneto breaker points to .015 inch using feeler on wrench provided. Set both magnetos so that the breaker points are just about to break for No. 1 position. 4. Insert the magneto drive shaft for each magneto into its socket. 5. Put the couplings on the drive shafts. The drive shaft has nineteen teeth and the magneto gear twenty teeth. If the magneto gear will not slip into the coupling without turning, turn the coupling a tooth in the direction of least discrepancy and try again. After several such trials the magneto may be coupled so that the magnetos fire within ½ degree of each other or absolutely in time. The rear plug in the cylinder should fire slightly before the front plug. The right magneto fires the rear plug and its breakers should open about ¼ degree to ½ degree before the left magneto breakers. Where a dial is not

used to obtain great accuracy it is sufficient to time one magneto and synchronize the breakers of the second magneto with the first by use of cigarette paper. Always check the timing before starting the engine after retiming. 6. Secure each magneto by the four cap screws through the bottom of the bracket and secure the cap screws by wire. 7. Place the terminal

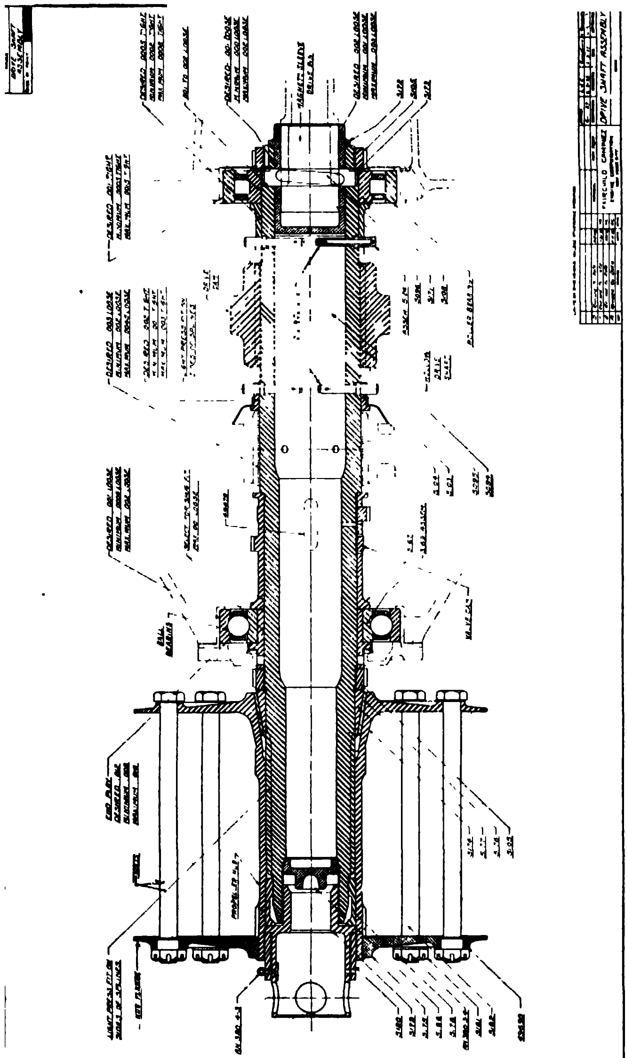


Fig. 551.—Driveshaft Assembly of Fairchild-Caminez Engine Showing Bearing Mountings, Drive Cam Retention Means and Propeller Hub Design.

blocks in the magnetos making sure that the members of the blocks match the members on the magnetos. Make sure that the ignition wire locking screws are all tight and especially that the screw in the "H" terminal is screwed in tight if the terminal is not used. A loose screw will wreck the magneto if it falls into the rotating parts.

Lubricating Oil Pump.—The lubricating oil pump can be assembled in only one way. See Fig. 545. The narrow gears go in the bottom half and the steel separating plate sets into the recess in the bottom half. The relief valve should be set with some compression on the spring but the pressure is not set until the engine is run on the stand or in the plane. Lubricating oils used in the "Cam" engine should have a viscosity of 120 to 130 sec. Saybolt at 210 degrees Fahrenheit. Operators of Cam engines should be very particular as to the specifications and qualities of the oil they are using. Oils should be purchased by specification rather than by trade name as the blends of blended oils are frequently changed. Any questions in regard to lubricants should be referred to the Material Department, Fairchild-Caminez Engine Corporation, Farmingdale, Long Island, N. Y.

Intake Manifold.—The intake manifold is an aluminum casting which fits into the rear half of the cam case and is connected by short pipes to the separate cylinders. Two passages are contained in this manifold which connect to the separate barrels of the duplex carburetor by means of short pipes passing through the oil sump of the cam case casting. The hot oil in the sump provides a hot spot above the carburetor flange—the carburetor being bolted directly to the case beneath this oil sump. Passages in the manifold are so arranged that opposite cylinders draw from the same carburetor barrel, with the result that no overlapping suction occurs and good distribution is obtained.

Carburetor Specifications.—The specifications given later for the different conditions of operation of these carburetors have been evolved after a great deal of painstaking effort by all parties concerned in the production and operation of the engines and carburetors, and represent the combined result of much dynamometer, torque stand and flight work. The specifications should, therefore, never be changed unless absolutely necessary, and then only when sufficient data are at hand to determine exactly the nature and extent of the change. These specifications are usually given on an aluminum tag riveted to the carburetor. The carburetor is of the two-barrel or duplex type, each barrel being in itself essentially a separate carburetor. The barrels have an actual internal diameter of 2$^3/_{16}$ inches and the throttles are placed on the same shaft and are consequently operated by a single lever. The common float chamber is placed between the barrels, this construction giving a uniform action under the different angles assumed by the airplane when on the ground or in normal flight. A single mixture control, of the back suction type, is used, this being possible since the two barrels draw from the common float chamber. The operating action of the throttle and mixture control levers is fore and aft. The internal specification or setting in the carburetor has been worked out to fit the requirement of the Cam engine. A 1$^{11}/_{16}$-inch venturi and a No. 39 Main Metering Jet should be used.

For starting the engine the general practice given in the chapter on Stromberg carburetors is recommended. It can readily be seen that with the low speeds used in cranking, it is much easier to start the idle system to functioning than the main well. In starting, therefore, the throttle should be kept closed, or nearly closed, at least until the engine fires.

Service Operation.—It has been found in service that there are several points, more particularly pertaining to adjustment, which require attention in order to obtain the best results from the carburetor. The idle adjustments on these carburetors cover a wide range and it is possible to make the mixture furnished the engine at the lower idling speeds either quite excessively rich or lean. Both conditions have a noticeably bad effect on the operation, not only on the idle itself, but on the acceleration and other factors of performance. The correct condition is, of course, that which provides just the right mixture to make the engine idle smoothly and regularly. This is usually a compromise as the engine requires a leaner mixture when hot than when cold.

The actual regulation should be made working with both the idle adjustments and the throttle stop adjustment. The throttle stop adjustment is easily recognized, being a small screw fastened in an arm rigidly connected to the throttle shaft. In the closed throttle position this screw strikes against a small steel stop cast into the body of the carburetor. The regulation of this screw, therefore, determines the minimum throttle opening. When the engine is in good condition with no manifold leaks, a good regular and positive idle can be obtained at approximately 250 r.p.m. (500 r.p.m. on tachometer) with spark advanced. With the mixture adjusted correctly, there should be no excess of black smoke or tendency toward "loading up" from a too rich mixture or irregularity from a too lean mixture.

At the lower idling speeds, it is not possible to make all of the cylinders fire with equal strength. Due to the low velocity in the manifold, it is the tendency of the heavier parts of the mixture, that is, the liquid particles, to collect and run to the bottom cylinders. These cylinders will, therefore, always be the richer. If, in addition to this natural condition, there are any manifold leaks around the top cylinders, they may not fire due to a too lean mixture. There is always a normal air leakage by the valve stems and a certain amount of exhaust gas dilution due to the overlap of the valves. A little careful observation and experiment will soon show what adjustment is best for any particular engine. In this connection, account should be taken of the other factors of performance, notably acceleration. If the idling mixture is either excessively rich or lean, the acceleration on a quick opening of the throttle from the lower idling speeds may be bad. Acceleration is also greatly affected by the fuel level in the carburetor. To obtain the best acceleration, the level should be as high as possible. The limiting factor in this respect is, of course, the stipulation that there be no flooding when the carburetor is tilted at any angle of normal flight. The correct level to fulfill these conditions is $1\frac{1}{2}$ inches below the parting surface of the two halves of the carburetor. A tolerance of $1\frac{1}{16}$ inches in either direction is allowed.

The specific gravity of the fuel used, as well as the fuel pressure, have a noticeable effect on the level. The level will be lower as the fuel is heavier. The carburetor as originally supplied has the level set for a very good (that is, light weight) grade of aviation gasoline. The use of fuel with a higher specific gravity will cause an excessively low level. High fuel pressure at the carburetor inlet will cause a high fuel level. If a fuel pump

is used, three pounds per square inch in pressure at the carburetor is recommended. If a gravity fuel system is used the outlet of the fuel tank should be at least one foot above the carburetor fuel inlet.

Carburetor Settings.—It is, therefore, best when indications of poor acceleration are present and all readily visible causes have been eliminated

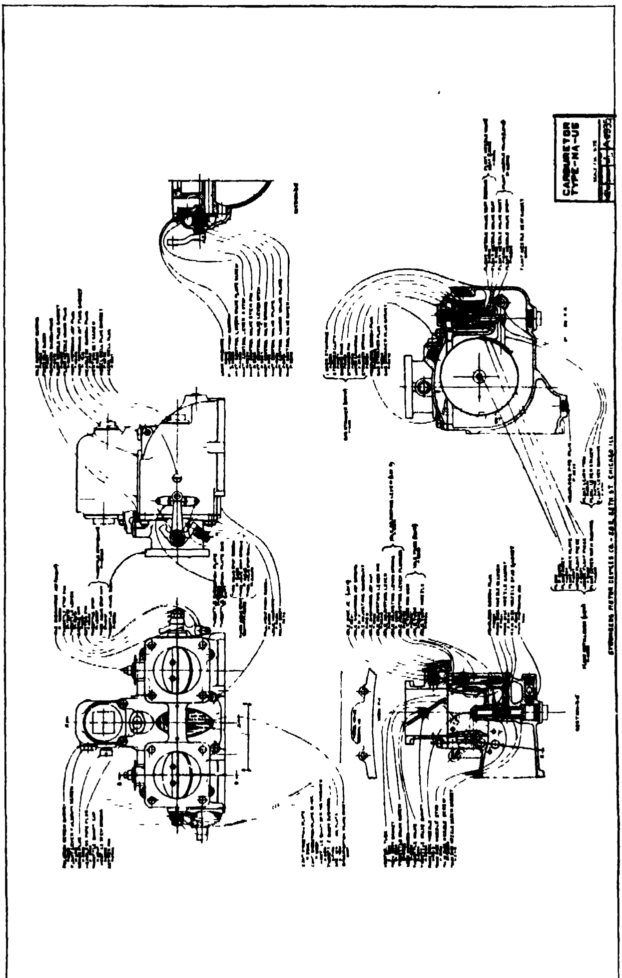


Fig. 552.—Stromberg Carburetor Type NA-U5 Used on Fairchild-Caminez Engine.

to check the fuel level. This can be done with the carburetor on the engine, though it is usually better to remove it and set the carburetor on the work bench with the necessary equipment. The check should always be made under conditions similar to those of actual operation; that is, with the same fuel as used in the engine and with the same fuel head on the carburetor as is actually present at extreme low idle. If the level is not correct, it

should, of course, be made so. The settings in these carburetors were determined using a good grade of aviation gasoline and as far as possible allowance was made for a normal variation in weather conditions. For operation in extremely cold weather or with inferior gasoline or combination of both conditions, it may be found necessary to use larger metering jets.

The ideal aimed at is, of course, the minimum possible fuel consumption consistent with good engine performance. Check the carburetor first to determine what metering jet size is actually in place. If the size is that given as correct for the particular conditions under which the carburetor is operating, the main metering jets may be removed and jets of two drill sizes larger substituted. Metering jets should never be drilled out. New metering jets of the size desired should be obtained as there will be a great likelihood of large errors with uncalibrated jets. It should never be necessary to increase the main metering jets by more than two sizes and as an invariable rule, do not use a main metering jet more than four sizes larger than the standard specification. In any event pilots should be warned to use the mixture control as much as possible. The carburetors should at every opportunity be checked carefully to see that all parts, screws and connections are tight and that all controls are functioning properly. The fuel strainer in the carburetor should be cleaned regularly.

As noted under "Bench Inspection," in the carburetor chapter, the carburetors at any time it is deemed necessary, may be partially disassembled and given a thorough inspection to determine their condition. It is recommended that this be done in all cases of doubt. The operation of the engine depends to such a large extent upon the carburetor that its condition should be kept at all times as nearly perfect as is possible. For an overhaul, the carburetor should be almost completely disassembled so that the condition of every part can be determined. An aircraft carburetor which is properly overhauled should be in exactly the same condition as a new one. This requires a thorough knowledge of the carburetor and painstaking attention to every detail of disassembly, examination and re-assembly. The procedure given in chapter on Stromberg carburetors should be followed in all particulars.

The illustrations of the carburetor should be examined carefully, with particular reference to the actual mechanical construction so that the disassembly and re-assembly can be properly made. The carburetor has been designed in so far as possible to require no special tools. However, as is necessary for all good work, the best of tools should be used and only those which are exactly fitted to the work. Particular care should be taken to see that gasket surfaces are not injured. Especial carefulness is also required for the proper assembly and disassembly of the float mechanism. This is made of sturdy construction to stand hard service, but it is necessary for proper operation that it be assembled with the pivot accurately lined up, and the needle in its proper location at all positions of operation so that there is no tendency to bind. Be certain that the float does not rub on the carburetor walls.

To disassemble the Model NA-U5 carburetor shown at Fig. 552, it is necessary first to remove the eight fillister head screws which hold the two

halves of the carburetor together. Sometimes these halves stick after long service but will loosen easily with a few light blows from a rawhide mallet on the lower half, holding the upper half securely in one hand. Then unscrew the two plugs in the bottom of the main discharge nozzle bosses. Unscrewing the accelerating well screw will then allow the removal of the main discharge nozzle proper and the accelerating well screw. After these are out, the accelerating well stud should be unscrewed from the main discharge nozzle. The location of the gaskets removed should be carefully noted so that they can be put back correctly in place when the re-assembly is made. Remove the strainer from the strainer chamber.

The float assembly and float needle valve can be taken out by unscrewing the float fulcrum screw. Unless it is known that the float level in the carburetor is incorrect, it is not necessary to remove the float needle valve seat. This has been securely placed in the carburetor and is set at the proper position to maintain the correct fuel level. If an examination shows that a new needle is needed, it will then probably be necessary to remove the seat to reset the level and obtain a tight fit with the new needle. Remove the idle air bleeders and the idle tubes from the lower half. See that all drilled passages are open. The mixture control valve is opened to inspection when the cover plate is removed by unscrewing the small fillister head screws. The mixture control valve is individually fitted and is not interchangeable with valves from other carburetors.

If the throttle valves fit accurately and the throttle shaft works freely in its bearings, it is not necessary to remove these. In case of removal the throttles should be marked for refitting. These throttles are machined accurately at the exact angle they lie in the carburetor barrel (twenty degrees with the horizontal). The barrels are carefully finished with a reamer which is held to within five ten-thousandths of size. In the reaming, however, the barrels attain different degrees of heat and there may be slight variations in size. For this reason the throttles are each fitted individually on the original assembly. Therefore, when removing them, mark carefully so that each throttle is returned to the proper barrel with the proper face up and all points on the circumference in exactly the same location as before removal. The hexagon head plug which holds the idle adjustment assembly in place should be unscrewed and the assembly removed.

The assembly of the carburetor is, of course, just the reverse process given above with the following addition: after the assembly of the lower half, the float level should be checked and if not right corrected. As noted above, the obtaining of a correct float level is of the highest importance. In making the re-assembly, too much care cannot be exercised in seeing that all necessary gaskets are in place. There are many gaskets in the carburetor and the omission or improper placing of any one of those may cause complete failure of the carburetor action. In assembling the upper and lower halves of the carburetor together, it should be made certain that they fit well. It will be noted that the venturi tube is held in place by a shoulder machined on the tube itself fitting into a groove in the lower half. The thickness of the shoulder and the depth of the groove are nearly the same so that the venturi will be held tightly in place and will not move under

vibration. Check carefully to see that the venturi shoulder will not hold the two halves apart, for should it do so, the resulting action will be the same as that from an imperfect main body gasket.

QUESTIONS FOR REVIEW

1. What is the distinctive feature of the Fairchild-Caminez engine?
2. How are low propeller speeds obtained in the Caminez engine?
3. Why are valve timing cams driven directly from the engine drive shaft in Caminez engine?
4. Describe lubrication system of Caminez engine.
5. What is the normal oil pressure of the Caminez engine?
6. Outline steps in starting Caminez engine.
7. Describe periodic inspection procedure for Caminez engine.
8. When is top overhaul necessary?
9. Outline steps in a complete overhaul of the Caminez engine.
10. How is Caminez engine timed?

CHAPTER XXXIII

WRIGHT WHIRLWIND ENGINES

Wright "Whirlwind" J4A Engine—Wright J5 Engine Features—Specifications, J4A, J4B and J5 Engines—General Description—Cylinders—Crankcase—Crankshaft—Valve Operating Mechanism—Connecting Rods—Pistons—Valve and Springs—Ignition—Fuel Pump—Induction System—Lubrication System—Accessories—Whirlwind Engine Troubles—Engine Fails to Start—Low Oil Pressure—Crankcase Filling with Oil—Engine Runs Unevenly—Excessive Oil Temperature—Carburetor Leaking—Cold Weather Cautions—Inspection Routine—Daily Inspection—After Twenty Hours—Complete Overhaul—Disassembly and Inspection—Whirlwind J5 Cylinders—Whirlwind J4A and J4B Cylinders—Nose Plate—Crankcase Front Section—Intermediate Section—Connecting Rods—Master Rod—Crankshaft—Inspection—Replacement of Valve Guides—Assembly of All Parts—Valve Operating Mechanism Adjustments—Timing—Installing J4B Cylinders on J4A Engines—Wright J5 Carburetor—Carburetor Overhaul—Carburetor Reassembly.

The current Wright "Whirlwind" Model J5 is the result of seven years' intensive development on one type of engine without alteration in bore and stroke and without changing any basic feature of the original design. The development contract under which this series of models began was dated February 28th, 1920. Since that time seven successive models have been developed and several thousand engines sold, practically all going into immediate service where thousands of flying hours have been accumulated. This service testing in the hands of the United States Navy and many commercial interests has resulted in a wealth of practical experience and technical data, which has formed the groundwork for further improvement in detailed design. These improvements have first been developed and tested in the laboratory through extensive dynamometer trials and later supplemented by flight tests where average service conditions were simulated. When conclusively proven, the changes have been definitely adopted as standard and made a feature of the next production run of engines.

This policy of gradual improvement and perfection has resulted in a sound development where each successive model has contained improvements dictated by service experience with the preceding engine, and in which each model has been uniformly successful. No other American air-cooled engine has such a history; in fact, the successful development of the Wright "Whirlwind" engine has been largely responsible for the American acceptance of air cooling as an ideal for aviation service. At the close of the World War the entire American aircraft engine industry was concentrated on the production of water-cooled engines. This concentration was logical, since the early American aircraft engines using the water cooling principle had been more successful than the early attempts at the use of air cooling. Up to this time no American air-cooled engine producing more than 100 horsepower had been successfully constructed, and it was generally felt that the expense of developing this principle, with the attendant difficulties, would be so great as to be unwarranted by the funds available at that time. It is fortunate, however, that among those responsible

for the future success of American naval, military and commercial aviation were a few farsighted men whose faith in the principle of air cooling led them to devote their time and the funds available to further development of this type of engine.

In 1916 Mr. Charles L. Lawrance started a development of air-cooled engines of small power. His early experiments led him to the belief that larger powers could be successfully constructed, and it was largely through his efforts that an experimental contract for the development of a nine-cylinder, 140-horsepower air-cooled radial engine was awarded by the United States Army early in 1920. Immediately thereafter the United States Navy also gave Mr. Lawrance a contract for a similar type of engine to have a guarantee of 200 horsepower at 1,800 r.p.m. These two engines were developed simultaneously and both passed their 50-hour acceptance

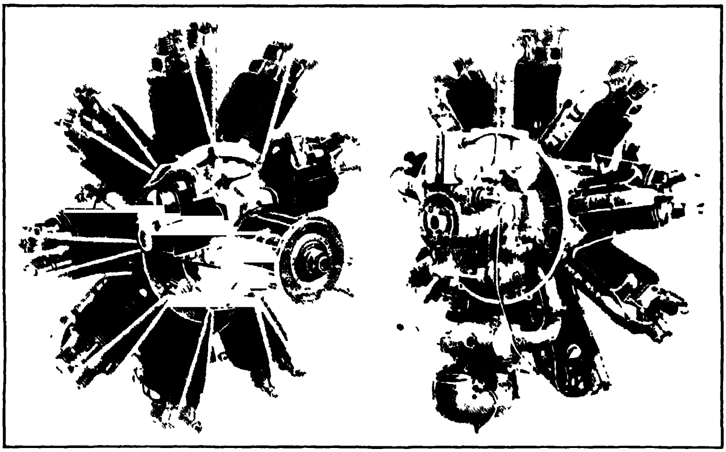


Fig. 553.—Wright "Whirlwind" J4 Radial Cylinder Engine. At Left, Viewed from the Propeller End. At Right, Rear View Showing Carburetor and Induction System. Note Differences in Detail with J5 Models.

tests early in 1921. This second engine, designed and constructed for the United States Navy, was the forerunner of the now famous series of Wright "Whirlwind" engines, having a bore of 4½ inches and a stroke of 5½ inches, and rated at 200 horsepower at 1,800 r.p.m. Since that time eight successive models have been produced without alteration in the basic design. These models have been the J1, J2, J3, J4, J4A, J4B, J5 and J6. Each model has been produced in quantity for the United States Navy before being released for commercial sale. In this way commercial aviation in the United States has been given the benefit of time-tested engines of a design already approved and tried by the United States Navy. The current models, J5C, J5CA and J6 combine all the experience with the preceding engines and constitute a refinement which goes far beyond their capabilities.

It is the policy of the Wright Company to incorporate engine improvements and minor new developments in their engines as rapidly as possible. To designate each factory run of engines of exactly the same detailed design, capital letters are added to the basic model designation. In this way

the Model J4A was a refinement of the Model J4, and in a similar way the Models J5C and J5CA indicate minor modifications of the basic Model J5 design. The rapid development of American commercial aeronautics came coincident with the Wright "Whirlwind" Model J4B, and it was this engine which was so successfully and so widely used in commercial enterprises during the year 1926. In competition with war surplus engines at much lower first cost, the Wright "Whirlwind" has demonstrated its outstanding efficiency to such an extent that many commercial interests have disregarded the higher original investment and gained their increased profits through lower operating expenses throughout the greater life of the "Whirlwind" engine. It has frequently been proven that the operation expense of a modern air-cooled radial engine is much lower than that of the war surplus water-cooled type; that its ultimate life is much greater; that the differential in first cost is rapidly overcome; and that in the end the modern air-cooled engine will prove more economical. Well proved planes from the designs of leading American manufacturers, powered with "Whirlwind" engines for every type of flying, including open sport planes, closed family and passenger planes, cargo planes, seaplanes, planes that take-off from land or water, or big trimotor airliners, as comfortable as a yacht, are available.

To outline in any detail all of the record breaking performances of the Wright "Whirlwind" motor requires more space than is available in a book of this character but some of the feats performed by pilots having planes equipped with this powerplant, as enumerated below were epoch making in character and should be mentioned briefly.

On May 9th, 1926, Commander Byrd and Floyd Bennett flew from King's Bay, Spitzbergen, to the North Pole and return in fifteen hours and 30 minutes. A Fokker monoplane, equipped with three Wright "Whirlwind" engines, was used.

On April 12th, 1927, the Wright-Bellanca cabin monoplane, with Clarence Chamberlain and Bert Acosta as pilots, took off from Roosevelt Field, N. Y., and established a world's record endurance flight of 51 hours, 11 minutes and 25 seconds, exceeding the previous record by approximately six hours. The plane took off with a useful load of over 2,900 pounds, including 385 gallons of fuel.

On May 20th, 1927, Captain Charles A. Lindbergh took off alone from Roosevelt Field, N. Y., in his Ryan monoplane, "The Spirit of St. Louis," and landed at Le Bourget Airport, Paris, France, 33 hours, 29 minutes and 30 second later, having covered a distance of 3,610 miles. 381 gallons of fuel and 11.8 gallons of oil were consumed in this flight.

On June 5th, 1927, Clarence Chamberlain, with Charles A. Levine as passenger, completed a nonstop flight from Roosevelt Field, N. Y., to Eisleben, Germany, a distance of 3,905 miles, in about 43½ hours. The Bellanca monoplane which had previously established a world's endurance record, was used for this flight.

On June 29th, 1927, Lieutenants L. J. Maitland and A. F. Hegenberger completed a nonstop flight of 2,400 miles from Oakland, California, to Oahu, Hawaiian Islands, in 25 hours, 50 minutes. A Fokker monoplane

Army transport, equipped with three Wright "Whirlwind" engines, was used for this flight. 920 gallons of fuel and 21 gallons of oil were consumed by all three engines.

On June 29th, 1927, Commander Byrd, accompanied by Bert Acosta, G. O. Noville and Bernt Balchen, took off from Roosevelt Field, N. Y., in a Fokker monoplane with three Wright "Whirlwind" engines, for Paris. After arriving over France, they were unable to locate Paris due to low-lying clouds and heavy rain. Turning back towards the coast, they landed at Ver-sur-Mer, after some 43 hours in the air.

On July 13th, 1927, Ernest L. Smith and Emory B. Bronte took off from Oakland, California, in a "Whirlwind" engined Travel Air monoplane, and landed on the island of Molokai, Hawaiian Islands, 25 hours and 36 minutes later. In this nonstop flight, 2,348 miles were covered.

In the National Air Tour, June 27th to July 12th, 1927, Edward A. Stinson, in a Stinson monoplane with a "Whirlwind" engine, won first place with a score of 97% of the possible maximum. This plane attained a high speed of 124.3 miles per hour with 1,500 pounds pay load and a total of 2,275 pounds useful load. This tour of over 4,000 miles, covered eighteen states and one province of Canada. Twelve of the fourteen planes competing were equipped with Wright "Whirlwind" engines.

On December 13th, 1927, Colonel Charles A. Lindbergh flew from Washington, D. C., to Mexico City, Mexico, in his Ryan monoplane, "The Spirit of St. Louis," as the initial flight of a goodwill tour of the Pan-American countries. Exactly two months later, February 13th, 1928, Colonel Lindbergh arrived safely in St. Louis, after having visited seventeen cities in fourteen countries and having covered 9,390 miles. Starting New Years Day, Jan. 1st, 1929 a Fokker "Whirlwind" trimotor monoplane, in charge of Major Carl Spatz of the U. S. Army remained in the air for 154 hours and 40 minutes, breaking all world's records for extended flight for any type of aircraft.

This chapter, which has been reproduced from the makers instruction manual through their courtesy is included in this treatise with the intention of providing the necessary instructions for operating and overhauling Wright "Whirlwind" engines, which are so widely distributed, and which have so many records to their credit.

It is intended primarily for the use of those in charge of a number of engines but it covers the whole field. The airplane designer will find information helpful in providing the best installation in the chapter to follow on that subject, the pilot will find instructions for handling the engine and the hangar men will find hints on its daily care. Perhaps the greatest attention has been given to the chapter on disassembly and inspection. The methods followed were decided after careful consideration of factory procedure and conditions in the field. Particular emphasis is given to instructions on some points which may appear to the reader to be of small importance. However, great care has been taken not to stress anything unduly. When small matters have been made very prominent it is because experience has dictated that these points must be given especial care. It has been assumed that the mechanic who does the work will be fully acquainted with

the grade of workmanship necessary for aviation engine repair, hence there is no reference to elementary points of craftsmanship. For further assistance, or for explanation of points not found to be fully covered, application should be made to the company's Service Department by writing the Wright Aeronautical Corporation, Paterson, N. J.

Wright "Whirlwind" J4A Engine.—Some years ago, through the foresight of Commander B. G. Leighton, then in charge of engine development for the Navy, the Bureau of Aeronautics gave the Lawrance Company an experimental contract for the development of a small nine-cylinder engine,

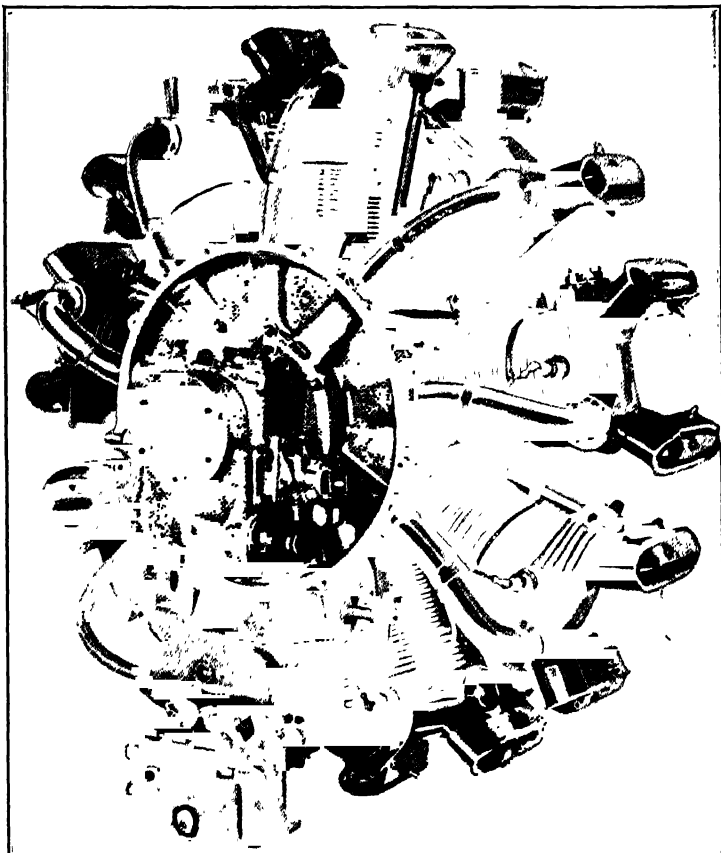


Fig. 554.—Wright "Whirlwind" J5 with Enclosed Valve Gear Viewed from the Rear.

using the cylinders developed for the three-cylinder engine. This engine was known as the J1. A number of these engines were put into Naval service, beginning about six years ago. The J1 was followed successively by the J3, J4 and J4A, which were developed by the Wright Company after its merger with the Lawrance Company and two recently designed forms the J4B and the J5 have also been developed. These engines are now practi-

cally standard in the 200 horsepower class, several hundred being now in service. To the Navy, therefore, should go the credit of first putting air-cooled engines to work in this country, though the Army used thousands in its aviation school system in France for training purposes. Owing to its use by the Navy and numerous commercial airplane constructors, the Wright "Whirlwind" series is probably the best known and most widely used of the contemporary radial designs. The J4A type is shown at Fig. 553 and the improved J5 is illustrated at Fig. 554. This differs from the earlier type in numerous detail refinements. The valve gear is enclosed and a three-barrel carburetor is used.

The problem of fuel distribution is an important one in radial engines. Various systems of gas distribution have been used. So far, the most satisfactory has been three separate three-cylinder induction systems, consisting of circular manifolds with cylinder leads 120 degrees apart, each provided with its own carburetor. If a single inlet-valve becomes inoperative, only three of the nine cylinders are affected. This system has the disadvantage of considerable weight and complication. A modification has been used by the Wright Company in which the three manifolds are connected to a single double-barrel carburetor in the J4A and there is very little more complication in the three-barrel type used on the J5 engine. A third system of considerable promise is the rotary distributing system, in which a single carburetor is used in conjunction with a small blower from which the gas is taken tangentially to the various cylinders. The blower not only distributes the gas uniformly, but thoroughly mixes the fuel with the air and prevents puddles of fuel from forming in the induction system. This system is used in the Pratt & Whitney "Wasp" engine as well as the Wright Cyclone, Bristol Jupiter and others.

The mechanical balance of a radial engine involves the use of counterweights. These are calculated so as to balance the entire weight of the connecting rods and the pistons attached to the crankpin. The center of gravity of this system travels approximately in a circle about the crankshaft so that practically perfect mechanical balance can be secured. It has been found that a fair approximation to this method can be secured by balancing one-half the reciprocating and all the rotating weight, considering it all to be on the crankpin. With the longer strokes, the travel of the center of gravity becomes an ellipse, so that it is necessary to determine upon the best circle and to make an approximation of the balance. The concentration of all the connecting rod weights upon one crankpin results in large counterweights; for example, a 1,650 cubic inch engine may require counterweights that weigh approximately 60 pounds. The cut-away sectional view of the J5 engine at Fig. 555 shows the construction of the counterweights and the big end of the master rod very clearly.

The design of the master connecting rod, Figs. 555 and 556 involves a study of knuckle-pin travel that is particularly interesting. The knuckle-pin adjacent to the master rod, which is usually put into the vertical or No. 1 cylinder, travels in nearly circular paths, while the pins for rods Nos. 5 and 6, which are at the bottom, have an ellipselike motion, with the long axis nearly at right angles to the cylinder center-line and considerably greater than the stroke. To equalize the compression ratio of the various

cylinders, it is necessary either to vary the knuckle pin centers with respect to the crankpin, or to use different heights of cylinder pads. As the motion of certain knuckle pins becomes more and more elliptical the farther removed they are from the crankpin, an effort is made to keep the crankpin small and the knuckle pins as close to the center of the pin as possible. The master rod necessarily receives considerable bending due to the forces applied by the link rods. For this reason it is necessary to make the master rod of considerable section in the shank. Due to this condition, trouble might be expected from the added sidethrust on the master rod piston. No difficulty is experienced from this in practice.

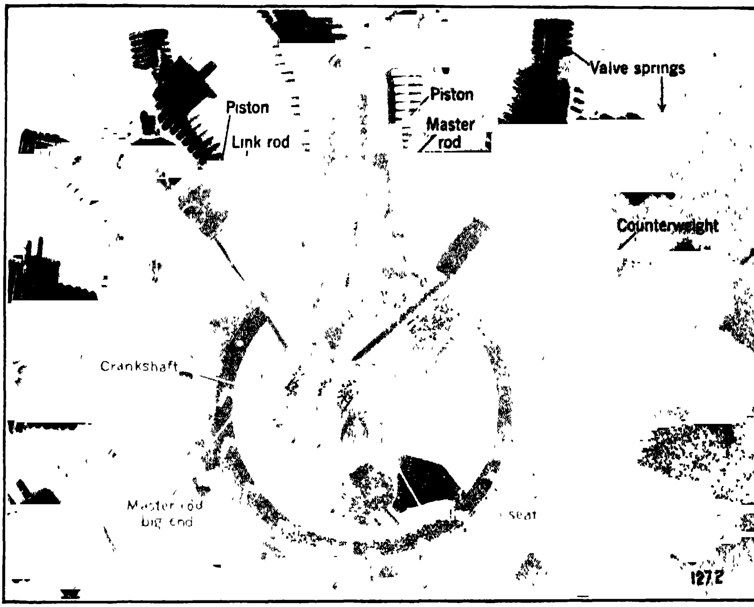


Fig. 555.—Part Sectional or "Cut Away" View of the Wright "Whirlwind" Engine Showing Connecting Rod and Crankshaft Assembly, also New J5 Cylinder Construction.

The general construction of the J4A and J4B engines can be understood by study of the transverse section at Fig. 557 and the section taken through the accessory drive casing at Fig. 558. The construction of the J5 "Whirlwind" engine can be grasped by inspection of the oiling chart in the chapter on lubrication systems. The dimensioned installation drawing at Fig. 559 is valuable in showing how compact this form of powerplant is. The table of specifications which follows is furnished by the Wright Aeronautical Corporation and gives detailed information regarding the three latest forms of "Whirlwind" engines. The J5 is the latest type and is the form that has superseded the J4A and the J4B engines. The differences in construction are all made clear in the specifications furnished by the makers.

Wright J5 Features.—The current Wright "Whirlwind" Model J5 shown at Fig. 560 which shows a front view and Figs. 561 and 562 which are sectional elevations is the result of eight years' intensive development on one type of engine without alteration in bore and stroke and without changing any basic feature of the original design.

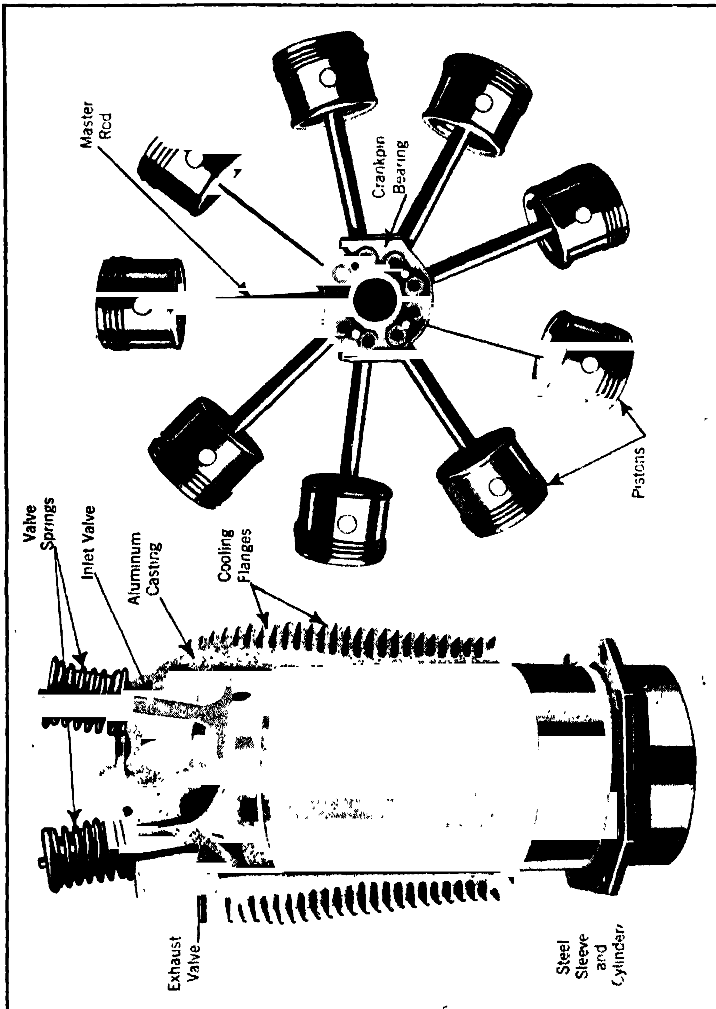


Fig. 556.—Sectional View of Wright J4A Cylinder at Left. View at Right Shows Master Rod Assembly with Pistons and Link Rods in Place.

The new features in the "Whirlwind" all aim at improved economy. A new cylinder design shown in sectional view at Fig. 561 gives cooling characteristics even better than those of the previous "Whirlwind" which, in conjunction with the new three-barrel single float carburetor, and the new induction system, gives a marked improvement in fuel economy. The

new enclosed valve gear gives economy in maintenance, as it keeps the dust, sand and moisture from the wearing parts, decreases the variation in valve clearance with temperature, and increases the length of time the valve gear can go without lubrication by hand. The durability of the valve operating mechanism is greatly increased by increasing all the bearing

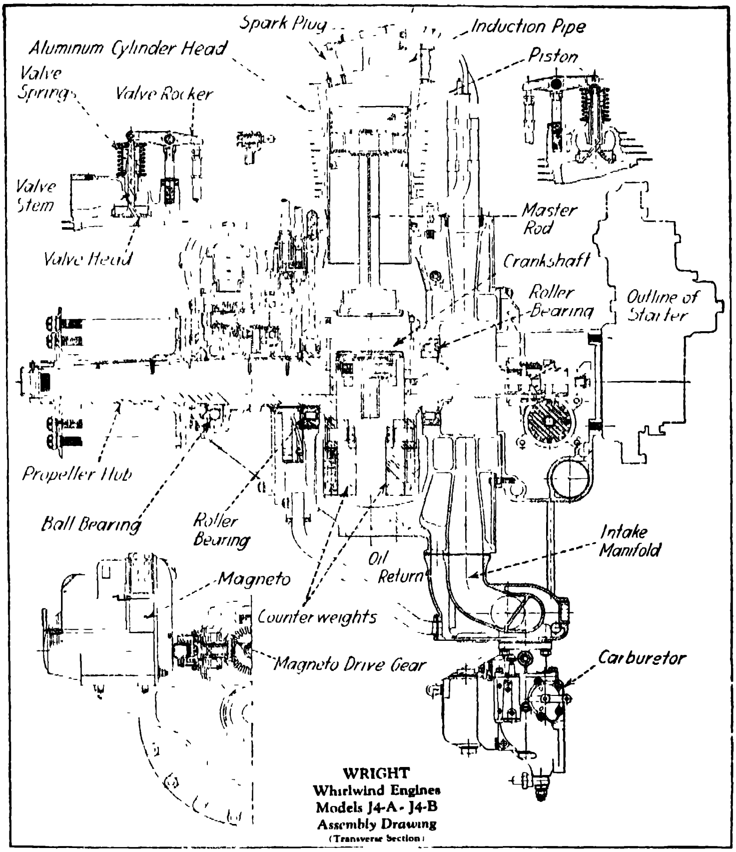


Fig. 557.—Transverse Sectional Assembly Drawing of Wright "Whirlwind" Engine Models J4A and J4B. Cylinder Construction is Now Different on J5 Engines.

surfaces, and using the most durable materials known. Many parts of the engine, such as the external oil pipe assemblies, have been redesigned for increased durability. With straight aviation gasoline, the average fuel consumption on production engines has been running between .5 and .55 pounds per horsepower hour at full throttle, and the fuel consumption at cruising speeds is so reduced that a plane can cruise on from eight to twelve gallons per hour per engine. All desirable accessories can be fitted immediately to this engine, including the Wright engine driven fuel pump, any standard type of gun synchronizer drive, any standard starter. A hub

for wooden propeller is standard but optional. Priming pump and fittings, tool kit, instruction book, magneto switch, the Wright carburetor air intake heater and a substantial shipping box are standard equipment.

It is doubtful if any other engine in the world has successfully undergone such long periods of full throttle endurance testing as the Wright "Whirlwind" engine. Three 50-hour full throttle endurance tests were run

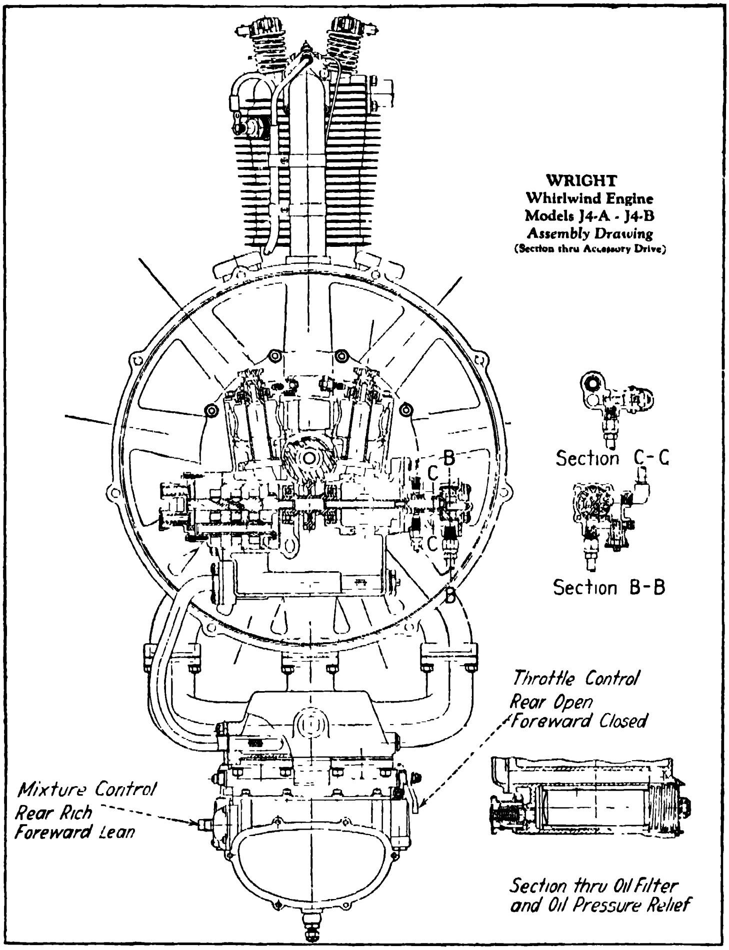


Fig. 558.—Assembly Drawing Showing Section Through Accessory Drive of Wright Models J4A and J4B Engines.

on the first experimental engine alone, in addition to 100 hours of miscellaneous testing. The first full throttle 50-hour test was run at 2,000 r.p.m., developing 239 horsepower with a fuel consumption of .508 pounds per horsepower hour. The second 50-hour full throttle test was run at 1,800 r.p.m., developing 216 horsepower with a fuel consumption of .458 pounds

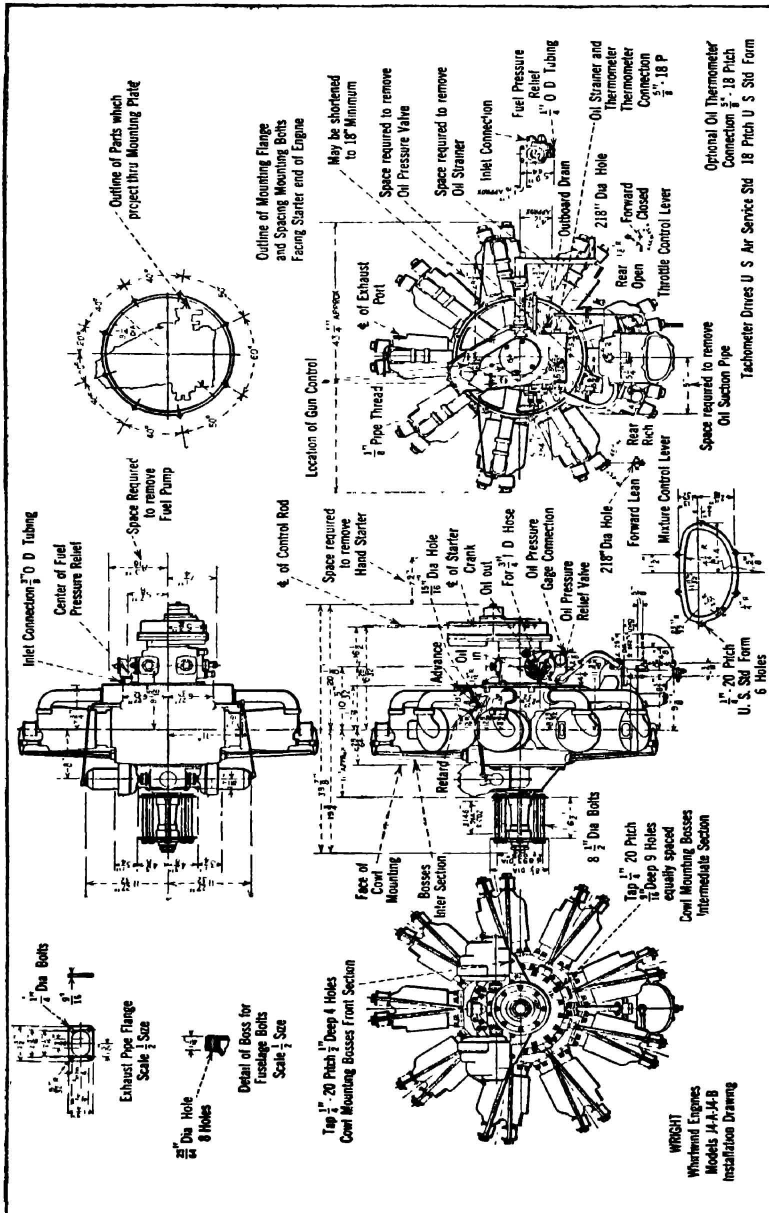


Fig. 559.—Installation Drawing of Wright J4A and J4B "Whirlwind" Engines.

per horsepower hour. The third 50-hour full throttle endurance test was an overload test using an external supercharger and developing 287 horsepower at 2,140 r.p.m with a fuel consumption of .504 pounds per horsepower hour. Since these tests were run, scores of these Wright "Whirlwind" engines have been tested extensively, both in flight and on the bench. They were first installed in a variety of military planes, and are now being daily installed in a wide variety of commercial aircraft.

Commercial aviation owes much to the broad and public spirited attitude taken by the U. S. Navy Department years ago in deciding to encourage the development of the Wright "Whirlwind" engine along such lines that it might be available at reasonable prices for use in commercial aircraft, as well as in naval and miltary planes. A detailed description of the new Wright "Whirlwind" Model together with illustrations of parts, operating suggestions and instructions for installation follows.

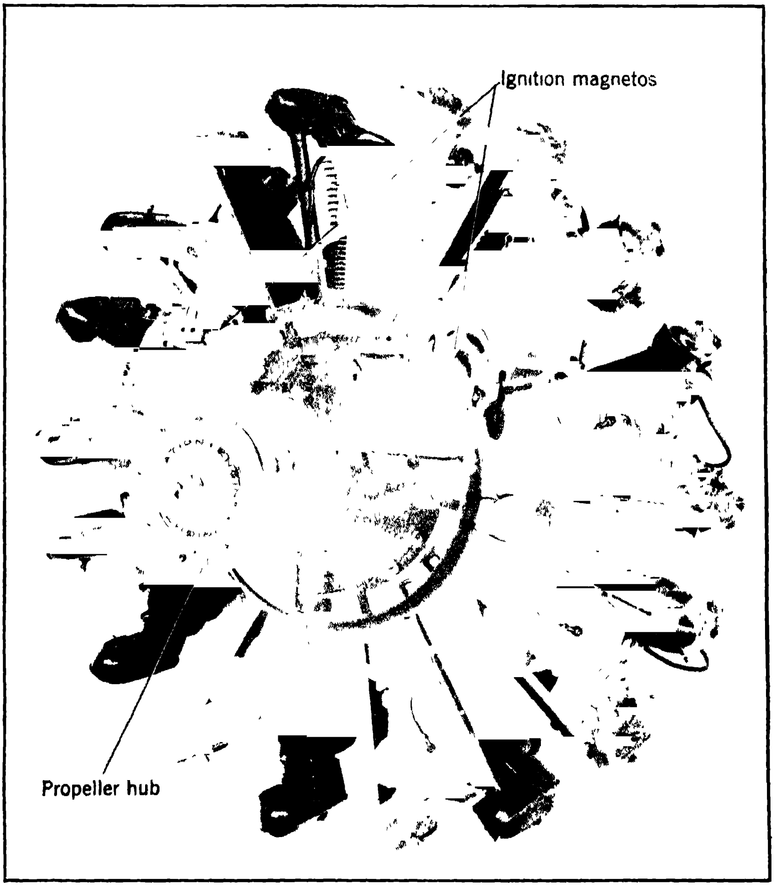


Fig. 560.—Propeller End View of Wright "Whirlwind" J5 Engine Showing Enclosed Valve Gear and Magneto Installation.

TABLE OF SPECIFICATIONS

For J4A, J4B and J5 Engines

GENERAL	J4A and J4B	J5
Average Hp. at Normal, R. P. M.	212 J4A 220 J4B	220
Type	Air-Cooled	Air-Cooled
1. Number of Cylinders	9	9
2. Bore	4.5"	4.5"
3. Stroke	5.5"	5.5"
4. Piston Displacement	788 cu. in.	788 cu. in.
5. Compression Ratio	5.3	5.4
6. Normal Speed in Revolutions per Min.	1800	1800
7. Guaranteed Brake Horsepower, Sea Level at Normal R. P. M. with Aviation Gasoline.	200	200
8. Direction of Rotation of Crankshaft (looking at propeller end of engine)	Anti-Clockwise	Anti-Clockwise
9. Direction of Rotation of Cam (looking at propeller end of engine)	Clockwise	Clockwise
10. Tachometer Shaft Speed	½ Crankshaft	½ Crankshaft
11. Direction of Rotation Tachometer Shaft (looking into open end of tach drive)	Anti-Clockwise	Anti-Clockwise
12. Average weight of engine complete with propeller hub, flange and bolts, carburetor and two magnetos. Without oil radiators, tanks, starting device, gasoline system, propeller, fuel pump or generator	478 lbs.	
13. Average weight of engine complete with carburetor, two running magnetos, sparkplugs, high-tension wiring and synchronizer drives. Without oil, exhaust pipes, exhaust flanges, starting device, fuel pump, propeller hub, flange and bolts (Propeller hub Assy. 13 lbs. additional weight)		500 lbs.
14. Diameter Mounting Bolt Circle	19¼"	19¼"
15. Number of Mounting Bolts	8 Total	8 Total
16. Size of Mounting Bolts	⅜"	⅜"
17. Overall Dimensions:	39⅞"	
Overall length of engine Aeromarine Starter Eclipse Starter	39⅜"	40 5/32"
Overall diameter outside of rocker arms	43¾"	45"
IGNITION		
18. Magneto Type	Scintilla	Scintilla
19. Direction of Rotation of Magnetos (looking at drive coupling end)	Both Counter Clockwise	Both Counter Clockwise
20. Magneto Speed	1⅛ Times Crankshaft	1⅛ Times Crankshaft
21. Magneto Breaker Point Gap:		
Splitdorf Magneto	.020"-.024"	
Scintilla Magneto	.012"	.012"
22. Sparkplug Point Gap	(A.C.) .020"-.025"	(B.G.) .015"
23. Spark occurs crankshaft degrees before top dead center	30°	30°

GENERAL	J4A and J4B	J5
VALVES AND TIMING (With hot or running tappet clearance)		
24. Intake Closes	60° A B.C.	60° A.B.C.
Intake Opens	8° B T.C.	8° B.T.C.
25. Exhaust Opens	60° B B C.	60° B.B.C.
Exhaust Closes	8° A T C.	8° A T.C.
26. Exhaust Remains Open (Crankshaft Degrees)	248°	248°
27. Intake Remains Open (Crankshaft Degrees)	248°	248°
28. Valve Lift	7/16"	½"
29. Valve Tappet Clearance (both valves)		
Hot or running clearance	060"	.060"
Cold clearance	010"	.040"
FUEL SYSTEM		
30. Carburetor Type	Stromberg NA-U5G	Stromberg NA-T4
31. Carburetor Settings.		
Venturi (choke)	1¾"	1 7/8"
Metering Jet	‡43	‡51
Accelerating Well Bore (Upper)	7/32"	¼"
(Lower)	‡14	‡14
Main Jet Air Bleed	‡53	‡55
Idle Metering Jet	‡58	‡60
Idle Air Bleed	‡50	‡40
Float Level below parting line	1½"	1 3/16"
32. Guaranteed Fuel-Consumption · Lbs. per Hp. Hour at 200 Hp. and Normal R. P. M.	.60	.53
33. Correct Pressure on Fuel Supply: Lbs per Sq In.	4	4
LUBRICATING SYSTEM		
34. Guaranteed Oil Consumption, lbs. per Hp Hr Not over	.025	.035
35. Correct Oil Pressure (lbs per sq. in.) at Normal R. P. M. at recommended oil temperature	60	60
36. Quantity of oil circulated per minute at normal pressure and temperature (lbs. per min.)	27	27
37. Minimum Safe Quantity of Oil in whole system, gallons	2	2
38. Maximum Permissible Outlet Temperature of oil under worst conditions+	180° F.	180° F.
39. Desired maximum oil outlet temperature in normal operation*	120° F.	120° F.
40. Speed of Oil Pump	Crankshaft Speed	Crankshaft Speed
41. Direction of Rotation of Oil Pump (looking at driven end of shaft)	Anti-Clockwise	Anti-Clockwise
42. Hose Connections Required between engine and lubricating system:		
Inlet and Outlet — Inside Diameter	¾"	¾"
Inlet and Outlet — Number of Pieces	2	2

43. Valve Spring Loading (Plus or minus 10%):

	Valve Closed		Valve Open	
	Length	Load	Length	Load
J5				
Inner	1 13/32″	8.4 lbs	1 3/32″	13 lbs.
Intermediate	1 13/32″	13.3 lbs.	1 3/32″	22.4 lbs.
Outer	1 13/32″	20.1 lbs.	1 3/32″	33.6 lbs.
J4B				
Inner	1 3/4″	15.1 lbs	1 5/16″	24.4 lbs.
Outer	1 3/4″	22.2 lbs	1 5/16″	37.9 lbs.

*Inlet temperature of oil will be approximately 10° F lower

General Description.—The Wright "Whirlwind" aviation engine is of the nine-cylinder, air-cooled, static radial type operating on the conventional four-stroke cycle. The bore is 4½-inch and the stroke 5½-inch, giving a total displacement of 788 cubic inches. The rated power is 200 horsepower at 1,800 r.p.m. The normal power at rated speed is 212 horsepower for the Model J4A and 220 horsepower for the Models J4B and J5. The guaranteed fuel and oil consumptions at rated power and speed are .60 pounds per brake horsepower hour and .025 pounds per brake horsepower hour respectively for the Models J4A and J4B. For the Model J5 these are .53 pounds per brake horsepower hour and .035 pounds per brake horsepower hour.

Cylinders.—The cylinders of Models J4A and J4B engines differ but slightly in several minor details. Service Instructions giving directions for installing J4B cylinders on J4A engines will be found in proper sequence. An aluminum alloy head and barrel with cooling fins cast integrally is served and shrunk onto a steel cylinder sleeve forged with a hold-down flange. Eight studs passing through this flange are used to fasten each cylinder unit to the crankcase. The cylinder head contains two ports, the axes of which are at right angles to each other. To the port facing aft is attached the induction pipe and to the port projecting in the plane of the cylinders is fastened the exhaust stack. Bosses within the ports receive the valve guides which are pressed into position. The inlet valve guides of all models are of bronze, while the exhaust are of bronze on the J4 series and tungsten steel on the J5. Valve seats of bronze are shrunk and expanded within the cylinder head. There are two sparkplugs per cylinder. In the Model J4A cylinder one bronze sparkplug bushing is screwed and pinned in the crown of the cylinder head forward of the inlet and exhaust ports. Another bushing of the same material is located in the rear side of the head with its axis 45 degrees to that of the inlet port. In the Model J4B cylinder the two bronze sparkplug bushings are diametrically opposite in the sides of the combustion-chamber and at an angle of 45 degrees to the crankshaft axis. **(Note:—The terms "right" and "left" refer to the view point of an observer facing the rear of the engine.)** The sectional view of a portion of the cylinder and cylinder head at Fig. 563

shows the method of securing the alloy head to the steel cylinder very clearly. The view at Fig. 556 shows the earliest type of cylinder construction, in which a long ribbed head casting is employed.

The Model J5 cylinder which is shown at Fig. 563 consists of a head with thirteen fins cast in aluminum alloy screwed and shrunk onto a forged steel barrel having thirteen machined fins and the hold down flange. The

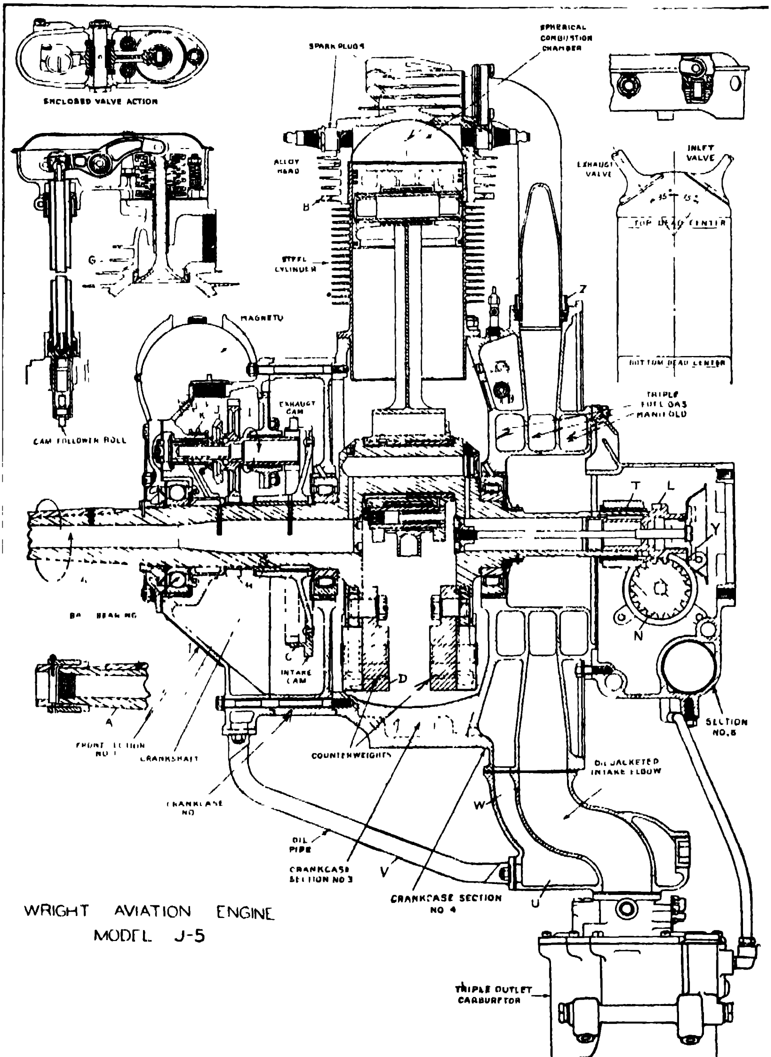


Fig. 561.—Transverse Sectional View of "Whirlwind" Model J5 Engine Showing Improvements in Cylinder Construction and Valve Gear.

combustion-chamber of this cylinder is approximately hemispherical with the valves inclined to the axis of the cylinder at angles of 35 degrees. The sparkplugs are located similarly to those of the J4B but at an angle of ten degrees to the crankshaft axis. There are no bushings, the plug being screwed directly into the aluminum cylinder head in the latest models though a bushing is shown in this illustration.

Crankcase.—The crankcase assembly is built up of five aluminum alloy castings held together by studs and nuts in generous quantity as shown at Fig. 561. The front section and nose plate include the thrust bearing housing, brackets for the magnetos and the magneto and cam driving gears. The intermediate section contains the cam and valve tappet mechanism and the front main crankshaft bearing housing. The main section is provided with the cylinder pads and contains the rear main crankshaft bearing housing and the induction passages. The rear section contains drives for the fuel pump, oil pump, gun synchronizers and tachometers. It also provides a mounting for the engine starter and a housing for the main oil strainer.

Crankshaft.—The crankshaft is of the single throw counter-balanced type machined from a chrome nickel steel forging and finished all over as shown at Fig. 564. It is hollow throughout its length and is used to distribute oil to all parts of the engine. The counterweights are bolted to extensions of the crank cheeks. The shaft rides in four bearings—the ball thrust bearing, the two main roller bearings, and a plain bearing in the rear section where the oil is admitted. The photograph shows the shaft and those parts which are assembled with it in the engine. Starting from the rear end these are the starter dog, accessories drive gear, retaining nut, oil slinger, rear bearing, front roller bearing, oil slinger (not visible), spacing ring (not visible), cam, cam drive gear, spacer, oil slinger, thrust bearing, oil slinger, thrust bearing nut, propeller hub key and propeller hub inner nut.

Valve Operating Mechanism.—On all "Whirlwind" models the cam is located in the intermediate section. It consists of a hardened steel ring with eight lobes on the outside and an internal gear cut on the inside. This is riveted to an aluminum hub riding on a steel sleeve on the crankshaft. The cam is rotated at 1/8 crankshaft speed in the opposite direction by a pinion on the cam and magneto drive shaft. The cam followers are of the conventional roller type and operate in cast iron (J4 series) or forged steel bushings (J5) which are a push fit in the intermediate section casting. The upper ends of the followers contain hardened steel sockets into which the lower push rod balls fit and in the lower ends are rollers which ride on the cam. The Model J4A and J4B push rods are equipped with a tappet clearance adjustment on the upper end, while those of the Model J5 are plain pieces of specially heat treated nickel steel tubing with balls pressed into either end. The J5 upper balls fit into hardened steel cups which are a loose fit inside the tappet clearance adjusting screws. The J4A and J4B rocker arms are carried in forked supports of forged steel. The J5 valve gear is semi-enclosed, the rocker arm housing also forming the support for the rocker arm pin. Tubular steel push rod housings are fastened at one end to the intermediate section and to the rocker arm housing at the other. Pressed aluminum covers are used on the rocker arm housings. The J5

cylinder and valve gear disassembled is clearly shown at Fig. 566.

Connecting Rods.—The connecting rods consist of one master rod and eight link rods machined from chrome nickel steel forgings. The master rod is provided with a steel backed babbitt lined bearing while the knuckle and wristpin bushings of the link rods are of bronze. The photographs at Figs. 555, 556 and 567 show the relationship between the parts very clearly,

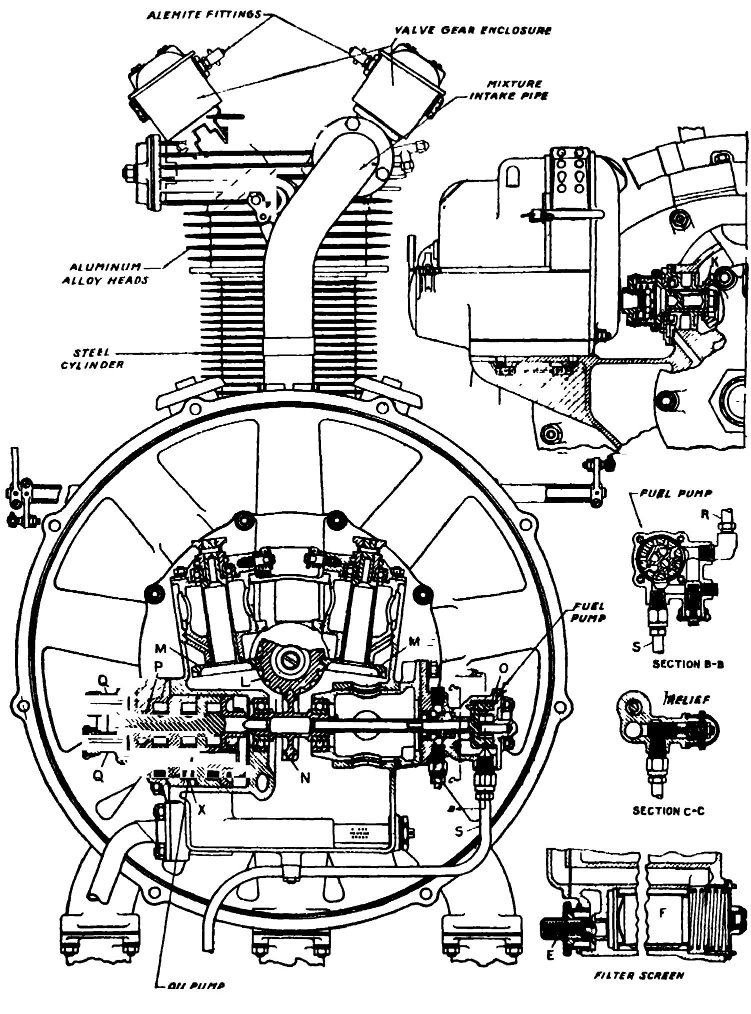


Fig. 562.—View of Accessory Drive of Wright "Whirlwind" Engine, also Location of Oil and Fuel Pumps.

the last mentioned having two link rods in place on the master rod.

Pistons.—The Model J5 pistons are of the conventional type cast in aluminum alloy. The inside of the head is heavily ribbed to obtain increased strength and to improve the cooling. There are two compression rings and one oil scraper ring above the pin and one compression ring at the bottom of the skirt. A groove around the piston just below the scraper

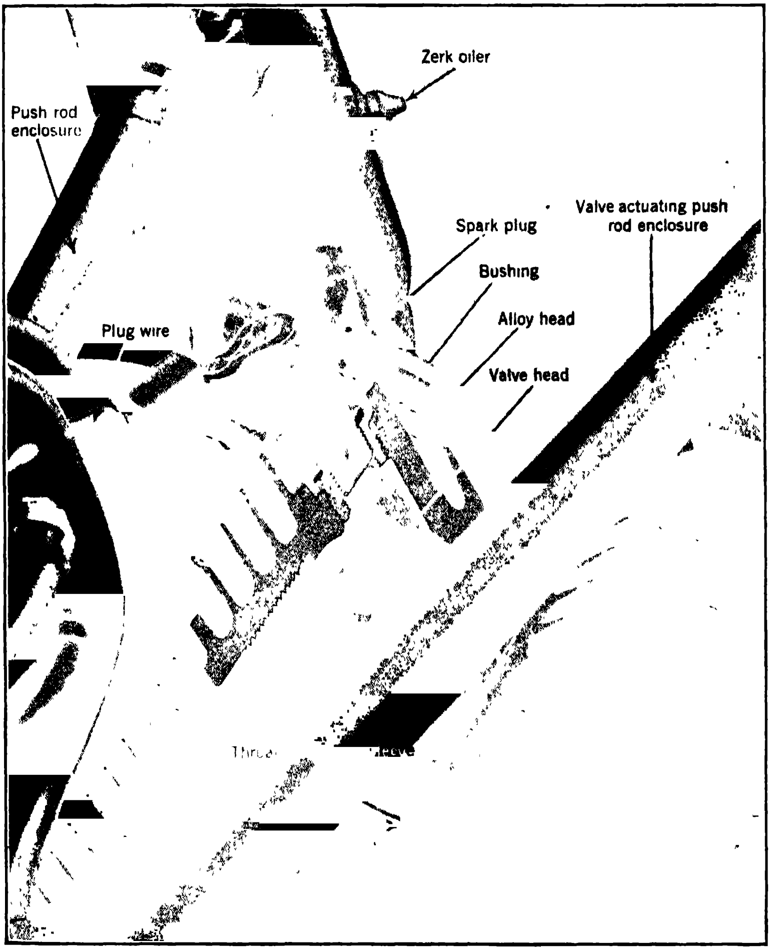


Fig. 563.—Cut Away Section to Show Construction of Wright "Whirlwind" J5 Cylinder.

ring and holes drilled through the wall return the oil to the inside of the crankcase. The piston skirt is provided with a series of shallow oil grooves to improve lubrication. The Model J4A and J4B pistons are of the same type, but without the ribs under the head or the oil grooves. The wristpins are of generous size machined from alloy steel stock and oil hardened. Aluminum alloy plugs in the ends prevent scoring of the cylinder walls.

Valves and Springs.—On Models J4A and J4B the intake valves are of tungsten steel and are of the mushroom type. The exhaust valves are of the tulip type in Silchrome steel. The Model J5 intake and exhaust valves are both of the tulip type and are of low tungsten and cobalt chrome (or high tungsten) steels respectively. The exhaust valves on the Model J5 are salt filled and sealed at the top with hardened plugs. The valve seats are annular rings of aluminum bronze of rectangular cross section. They are first shrunk into the cylinder head and then the small shoulder provided at the top is rolled over into an annular recess in the valve port to hold them positively in place. The valve springs on the Models J4A and J4B consist of two concentric helical coils of round steel wire per valve. The Model J5 has three springs per valve.

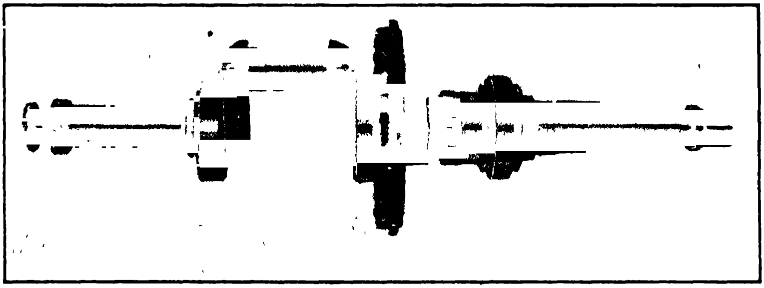


Fig. 564.—Crankshaft of J5 Engine Showing Relationship of Parts as Assembled in the Engine.

Ignition.—Ignition is furnished by two Scintilla AG9D magnetos mounted on the front section of the crankcase as clearly shown in cut away view at Fig. 568. The right-hand magneto fires the front sparkplugs (top plugs J4A) and the left-hand magneto fires the rear sparkplugs. The wiring is of the heavily insulated high tension type and is largely enclosed in metal manifolds.

Fuel Pump.—The Wright fuel pump is of the Viking internal gear type as shown at Fig. 569. This consists of an engine driven internal gear meshing with a contex gear which rides on a pin fixed in the pump cover. A crescent shaped boss on the cover fills the space between the two gears opposite the point of contact. Fuel is taken in at the connection on the side near the pressure relief valve, carried around in the gear 270 degrees and discharged through the connection near the bypass relief valve. The pressure relief valve, which is covered by a domed cap, can be adjusted to give any desired pressure in the discharge line. It consists of a plunger valve, a spring, an adjusting screw and a lock nut. The excess fuel coming through this valve comes out of the connection between the bypass relief valve and the mounting flange. (This connection can also be made at the opposite end of the same passage.) A bypass valve between the inlet and outlet passages enables the operator to pump fuel to the carburetor with the hand pump without forcing it through the gears. It is covered by a flat brass cap. The Stromberg NA-U5G carburetor is used on the Models J4A and J4B. It is of the double barrelled type and equipped with a me-

chanical economizer. The NA-T4 three barrelled carburetor is used on the J5 and will be fully described later in this chapter.

Induction System.—The carburetor is fastened to an oil jacketed manifold at the bottom of the crankcase main section. In the case of the double barrelled carburetor this manifold splits the two streams of vaporized fuel into three, and for the three barrelled carburetor it provides three unbroken passages as shown at Fig. 561. The rear of the crankcase main section contains three annular rings, each of which supplies fuel to three cylinders through steel intake pipes. The fuel is fed into the three rings through the branches of the manifold described above. As observed from the rear of the engine the left-hand passage supplies cylinders 2, 5 and 8, the middle passage supplies cylinders 1, 4 and 7 and the right-hand passage supplies cylinders 3, 6 and 9.

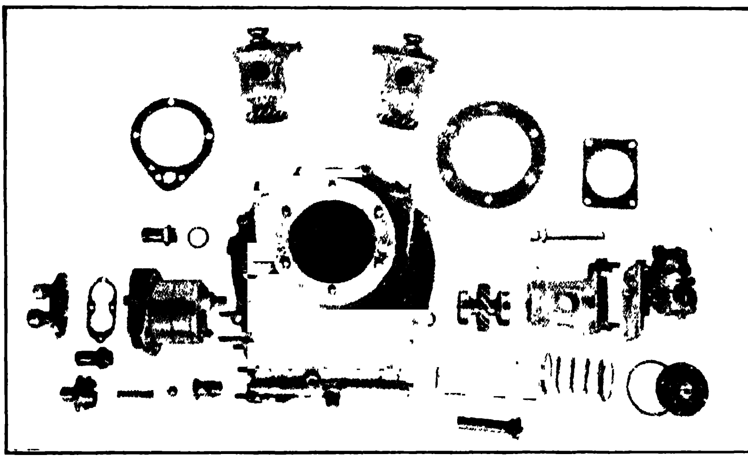


Fig. 565.—Rear or Accessory Drive Section of Wright J5 Motor Disassembled.

Lubrication System.—The lubrication system is of the full pressure type except for the cylinder walls, wristpins and accessories drive gears, which are lubricated by splash. Oil is carried in an external tank, not furnished with the engine. The oil is drawn from the bottom of the tank by the pressure pump and delivered to the annular groove around the rear (plain) crankshaft bearing at which point it enters the crankshaft. The crankshaft is drilled to supply oil to the connecting rod crankpin bearing, to the cam bearing and to passages near the front end of the crankcase which lead to the magneto drive bearings. Holes through the connecting rod bearing shell convey the oil into passages which carry it into the knuckle pins and thence to the knuckle pin bearings. The various gears, shafts and bearings in the crankcase, rear section, are lubricated by oil which sprays from the rear crankshaft bearing. Passages in the front section lead oil to the cam drive shaft and magneto shaft bearings, the spray from these and the cam bearing being utilized to lubricate the gears and valve tappets. Cylinders, pistons and piston pins are lubricated by spray from the crankpin bearing.

Rocker arm pins are provided with "Alemite" grease gun connections.

Accessories.—The crankcase rear section is fastened to the rear wall of the crankcase main section by five studs and two bolts. It contains the oil pump, oil strainers, oil pressure relief valve, fuel pump, gun synchronizers and the starter mounting pad. The photograph at Fig. 565 shows the rear section completely disassembled with the parts arranged to show their relationship to the assembly. Similar illustrations of the fuel and oil pumps will be found at Figs. 570 and 571, the latter showing the parts of the Viking fuel pump.

The crankcase rear section as shown at Fig. 561 is provided with a standard Army and Navy starter pad. Any one of several types of starters can be supplied at the option of the customer.

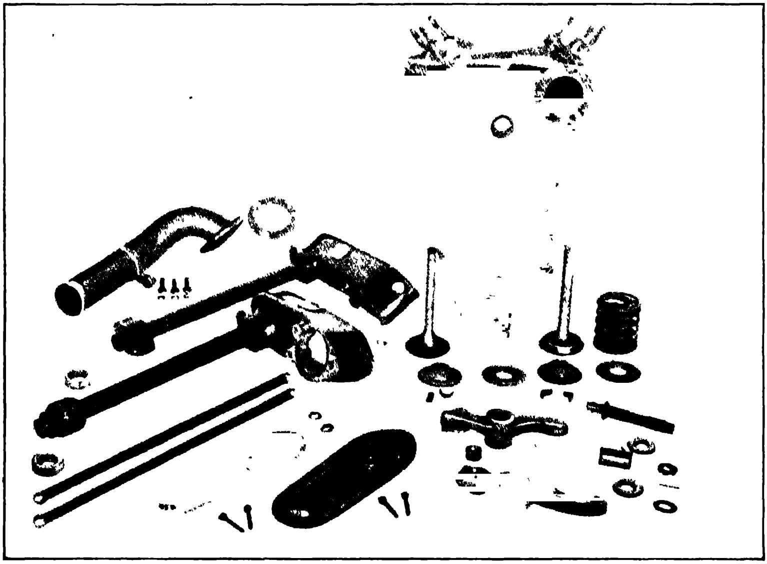


Fig. 566.—Wright Model J5 Cylinder and Valve Gear Disassembled.

The Wright Hand Starter was of the worm type with a gear ratio of six to one. (It was also supplied with a fifteen to one ratio for larger engines.) Running through the starter is a splined shaft, one end of which fits into the engine crankshaft. The other end holds a spring loaded clutch and a bronze housing carrying on one end of the starter worm gear, which engages with a worm on the hand crankshaft. The starting magneto, which is an integral part of the device, is also driven by the starting crank through gears. In starting, the worm is brought into contact with the worm wheel by pushing on the small rod beside the starting hand crank. Turning the crank then brings the worm into full engagement and further turning rotates the engine crankshaft. When the engine starts the worm is thrown out of engagement and slides along the cranking shaft to an inoperative position. The disengagement of the worm does not throw the starting magneto out of gear so it can be kept in operation by turning on the hand

crank until the engine has picked up enough speed to fire regularly on the running magnetos. The starting magneto is designed to operate in connection with a "trailing brush" on the running magneto which gives a greatly retarded spark, reducing the possibility of a "kick back" to a minimum. Should this occur, however, the engine and starter are protected against damage by the clutch which is designed to slip in such an emergency. An external ratchet on the cranking shaft positively prevents the crank from turning backwards. All parts are thoroughly lubricated by pressure feed from the engine oiling system. This starter is no longer supplied so the description given is intended to apply to those forms which have been produced heretofore.

"Whirlwind" Engine Troubles.—Determining the cause of engine troubles is at times rather involved on account of the number of sources to which a given symptom may be attributed. The best method of "trouble shooting" is to first decide on the possible causes and then eliminate them one by one, starting with the most likely. This table of the commonest troubles and their causes is submitted to the service men with the object of reducing wasted time and increasing the reliability of the "Whirlwind" engine.

If Engine Fails to Start it may be due to any one of the following causes:—1. *Lack of Fuel.* Examine fuel supply, shut off cocks, traps, strainers and hose connections. 2. *Under Priming* or *Over Priming.* See instructions on starting. 3. *Booster Magneto Defective.* Examine and test the starting magneto. 4. *Throttle Opening Incorrect.* The throttle should be approximately one-eighth open while starting. 5. *Defective Ignition Wire.* Examine ignition wiring for wear, breaks and incorrect connections. 6. *Dirty Sparkplugs.* Check sparkplugs for proper functioning. Clean and set gaps (B.G., .015-inch; A.C., .020-inch to .025-inch). 7. *Incorrect Valve Tappet Clearance.* Check the valve tappet clearance. 8. *Incorrect Timing.* Check valve and ignition timing. 9. *Water in Carburetor.* Remove a plug from the bottom of the carburetor and drain out gas and water. 10. *Cold Oil.* With the ignition switches off, turn the engine over by hand. If it is very stiff it will be necessary to heat the oil before starting. 11. *Magneto Breaker Points.* See that the magneto breaker points are clean and have the proper gap (.012-inch). Test spark delivered by magneto. 12. *Miscellaneous.* Examine the engine carefully for unusual conditions, turning over slowly by hand.

Low Oil Pressure or none at all may be caused by:—1. *Lack of Priming.* Disconnect the oil suction line and fill the pump with oil. Turn engine over by hand until oil is sucked into pump. Check oil supply. 2. *Leak in Suction Lines.* Examine the oil suction lines for air leaks. 3. *Dirt in Oil Screen.* Remove and clean the oil strainer. 4. *Oil Pressure Relief Valve.* Examine the oil pressure relief valve and spring for proper seating or breakage. 5. *Gun Synchronizers or Starter Dog Removed.* The gun synchronizers are on the main oil line and if removed should be replaced with dummy parts (No. 18,828). The same is true of the starter dog which should be replaced with part No. 19,987 and the retaining screw (J5 No. 19,712 or J4B No. 17,177). 6. *Crankshaft Plug Out.* Remove a cylinder and examine the crankshaft plugs. 7. *Excessive Bearing Clearance.* A bearing

may be worn enough to cut down the pressure in which case an overhaul will be necessary.

Crankcase Filling with Oil is usually caused by lack of priming in the discharge pump. Disconnect the main discharge line from the engine and put on a two foot length of garden hose. Feed oil into this hose while turning the engine backwards until a quart or so has been sucked in. Check oil pumps, strainers and lines for failures or stoppages.

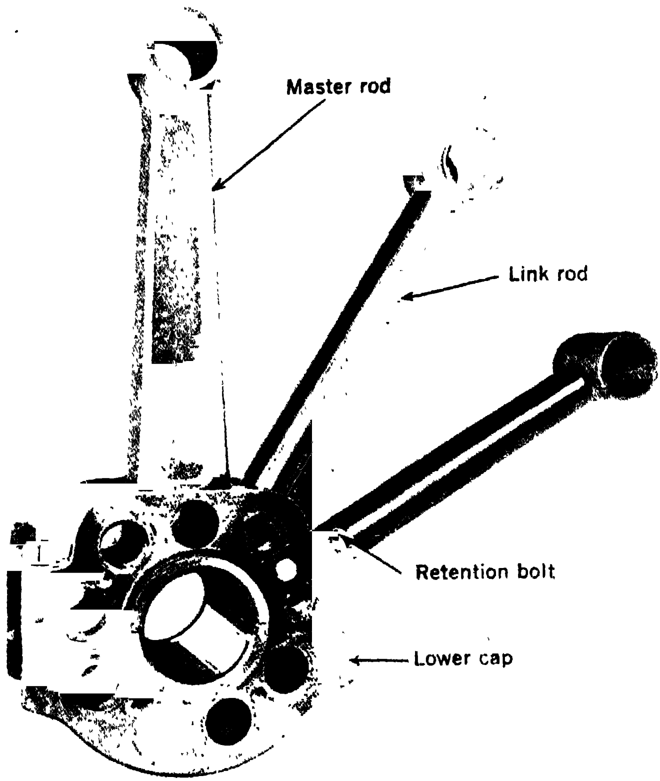


Fig. 567.—Master Connecting Rod and Link Rods Showing Method of Locking Knuckle Pins in Place in J5 Engine.

Engine Runs Unevenly and does not come up to power. The full throttle speed of the engine will vary 75 to 100 r.p.m. under different atmospheric conditions. It will also vary considerably with the condition of the propeller. Therefore the engine should not be considered low on power unless the drop in speed is excessive under similar conditions. Low power and uneven running may be traced to any of the following causes:

1. *Rich or Lean Mixture.* Make sure the mixture control lever is in the best position. 2. *Leaks in Induction System.* Examine the intake pipes for cracks and for leaks at the cylinder and crankcase connections. Examine

the carburetor and manifold flanges for tightness. Examine pipe plugs in cylinder inlet ports to see that they are all tight. 3. *Sparkplugs.* See that all the sparkplugs are clean and that they have the proper clearance.

4. *Valve and Valve Gear Trouble.* Check valve tappet clearance, springs, washers, rockers arms, and push rods. Be sure the push rods on J4 series engines have not been interchanged. The cam followers nearer the propeller operate the exhaust valves. See that the valves are not sticking. 5. *Poor Fuel.* Make sure the fuel being used is a good grade of domestic aviation gasoline and that it flows freely to the carburetor. 6. *Magneto Breaker Points.* See that the magneto breaker points are clean and have the

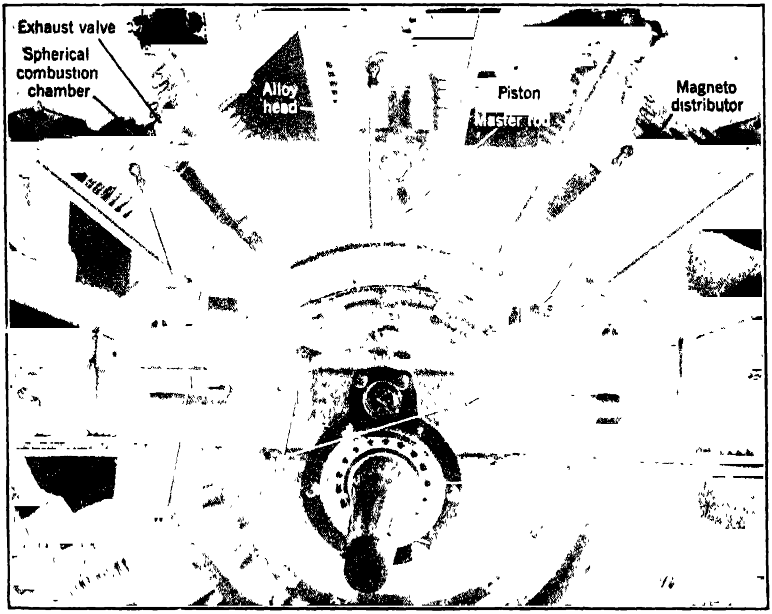


Fig. 568.—Cut Away View of Wright J5 Engine Magneto Installation and Cylinder and Piston Construction.

proper gap (.012-inch). Check operation of magnetos. 7. *Engine Overheating* This may be caused by items 1, 2, 3, and 5 above. It is easily recognized by the fact that the engine will run at normal speed just after idling and will then slowly fall off. Continued running of an engine exhibiting this symptom is liable to cause considerable damage so an investigation of the cause should be started immediately. Other causes are improper cowling, excessive air temperature, thin oil, and insufficient oil cooling.

It has been noted that a large number of airplane manufacturers do not install a shut-off cock in the primer line near the Lunkenheimer primer furnished with the engine. It is then possible for raw gasoline to be sucked into the engine causing roughness of operation. It is also possible for the leakage to be severe enough to cause dripping at the carburetor. The shut-

off cock should be installed in the line near the primer and should be provided with a right angled handle which in the "off" position will extend across the primer handle.

Excessive Oil Temperature may be caused by:—1. Insufficient oil cooling. 2. Insufficient oil supply. There should be at least two gallons of oil in the system. 3. Low grade oil. See that the oil being used is up to specification. 4. Suction pump failing to scavenge oil properly from crankcase. Examine all oil lines for leaks. 5. Overheated Bearing. If the trouble is not found after an investigation of 1, 2 and 3, a bearing may be overheating, in which case a disassembly will be necessary.

Carburetor Leaking.—Because of the fire hazard the engine should not be run if the carburetor leaks gasoline excessively. This may be caused by 1. Leaky float. 2. Stuck float. 3. Poor seating of needle valve. 4. Wear of float fulcrum pin. In any case the carburetor should be removed and checked over. If the float has been leaking the gasoline should be removed, the hole soldered, and the float immersed in hot water to test for tightness. The needle valve seat should be removed the valve lapped in with fine compound and the assembly tested for tightness and float level.

Cold Weather Cautions.—Under unusual weather conditions it may become necessary to adopt some method of heating the air entering the carburetor to prevent the formation of ice at the chokes. Wright Air Heaters No. 13,732 (J4B) and No. 13,828 (J5) have been found very satisfactory for this purpose. Due to the wide variation in engine installation requirements these heaters are furnished without pipe connections. In extremely cold weather it will be necessary to preheat the oil before starting. A great deal of time can be saved by draining the oil from the tanks as soon as operations for the day are concluded and before the oil has cooled off. If left in the tank over night it may become so viscous as to require considerable time to drain off. In cold weather it is also advisable to have some sort of lagging on all the external oil lines, especially the drain from the intermediate section to the sump. This will result in higher oil temperature at cruising speed and will decrease the danger of stoppage due to congealed oil. A layer of asbestos cord, shellacked and then wrapped with friction tape provides very good insulation. Lacking asbestos, several layers of ordinary packing cord can be used.

Inspection Routine.—In order to obtain maximum reliability and service from "Whirlwind" engines a regular schedule of inspections and overhauls should be maintained. Serious failures very often arise from minor causes which a few minutes inspection could have averted. The following schedule is suggested.

Daily Inspection.—Every flying day the following inspection should be made. Check all cylinders, one at a time in firing order (1, 3, 5, 7, 9, 2, 4, 6, 8), as follows:

Models J4A and J4B.—1. Does clearance between rocker roller and valve stem, on compression stroke, seem normal? 2. Are rockers free on shafts and lock wires secure? 3. Are rocker rollers free and lock wires secure? 4. Are valves free in guides? 5. Are valve springs and valve spring retainers intact? 6. Are rocker support lock nuts tight and are rocker rollers central on valve stems? 7. Are sparkplugs tight? 8. Grease rocker

shaft with Alemite gun using automobile transmission oil. 9. Oil rocker rollers with engine oil. 10. Are ignition terminals secure to wires and plugs and is insulation on wires intact? 11. Is compression normal?

After all cylinders have been checked proceed as follows:—12. Are carburetor and carburetor manifold tight at securing flanges? 13. Are fuel tanks filled? 14. Is oil tank filled? 15. Are magneto ground wires secure? 16. Are throttle, mixture and magneto controls free throughout their range? 17. What is full throttle r.p m.? 18. Is engine operation good on either magneto? 19. What are oil pressure and temperature? 20. What is gasoline pressure? (Should be two-four pounds per square inch.) The daily inspection of the Model J5 engine should include items 7, 8 and 10 to 20 inclusive.

Twenty Hours.—After every twenty hours of flight the valve gear should be disassembled and inspected as follows:—Models J4A and J4B. 1. Remove push rods and examine balls and ball sockets for wear. 2. Grease sockets in rockers. 3. Thrust lower ball ends of push rods in can of heavy grease and replace the rods in their proper sockets. 4. Make complete inspection as outlined for each flying day.

Model J5.—1. Remove the rocker box covers and make a check of the amount of motion of the various parts. If the tappet clearance seems normal it should not be disturbed. If any part seems to have too much motion, or if the tappet clearance is excessive, the rocker arm and push rod should be removed and the cause determined. Check the offending part against the maximum allowable clearance as indicated in the charts Figs. 573 and 574 and replace if this is exceeded or if in the opinion of the operator it seems advisable. The figures that are underlined indicate maximum allowable clearance due to wear before the part must be replaced.

After the valve gear has been inspected, repaired and re-assembled the following items should be checked (all "J" series models except as noted): —1. On J4 series engines check clearance between rocker rollers and valve stems with feeler and reset to .010. Be sure adjusting ball and lock nuts are tight. 2. Are sparkplug points clean and are gaps set at proper clearance (.020-inch to .025-inch for A. C. Plugs; .015-inch for B. G. Plugs). 3. Are nuts on inlet pipe upper flanges tight? 4. Are inlet pipe packing nuts tight? 5. Are cylinder hold down nuts tight? 6. Are fuel strainers clean? 7. Are fuel lines and connections secure and free from leaks? 8. Is lock on gasoline pump pressure adjusting screw secured? 9. Are oil strainers clean?

10. Drain the old oil from the tanks and lines and flush with kerosene until perfectly clean. (Do not use kerosene inside the engine.) Replace the lines and put two gallons of clean oil in the tank. Run the engine for twenty minutes and then drain out all the oil again. Replace the lines and fill the tank with clean oil. Great care should be taken to see that all the oil lines are replaced properly and there are no air leaks. Small air leaks are apt to interfere seriously with the proper functioning of the lubricating system. 11. Oil tanks should be drained and filled with fresh oil. 12. See that hand turning gear is well lubricated. 13. Are engine mounting bolts tight? 14. Does each magneto get full advance when operated from cockpit? 15. Are magneto breaker points clean and gaps set at .012-inch? 16.

Are magneto couplings in good condition? 17. Put four drops of medium machine oil in rear magneto oil holes. Fill front holes. 18. Are propeller hub lock nuts and propeller hub bolts tight? 19. Check the clearance between the rear of the rocker boxes and the cylinder heads and make sure it is .031-inch (Engine cold). While this dimension should not vary it is extremely important and should be checked carefully. Incorrect clearance is very apt to result in failure of the rocker box studs.

It is advisable to run the engine at part throttle for at least 1/4 or 1/2 hour twice a week in order to keep interior parts flushed with oil. This will prevent the vapor due to condensation in the crankcase from rusting steel parts.

Complete Overhaul.—It is suggested that the compression, as noted in Item 11 of the daily inspection, be checked very carefully on each cylinder. As soon as one is found to be low it should be removed, the valves tested for leakage and the piston rings checked for tension. The valves should be ground and the piston rings replaced when necessary. In this manner the engine can be kept up to power and speed. It is sometimes very difficult to distinguish between a valve which is leaking and one which is being held open by a bit of dirt or carbon on the seat. The only way to check this out is to run the engine for several minutes and then try the compression again. Experience with "Whirlwind" engines in service has indicated that the length of the period between overhauls is limited by the tendency of the lubricating system to fill up with sludge. This is composed of gums formed in burning the lubricating oil, carbon, lint and substances taken into the engine through the carburetor or breathers. After 200 hours of service the accumulation is likely to become severe enough to plug up one of the passages resulting in the seizure of the bearing whose oil supply is cut off. It is therefore recommended that "Whirlwind" engines be given a complete overhaul after every 200 hours of service.

Disassembly and Inspection.—After removing the engine from the ship, mount it on a tilting stand as shown at Fig. 577. The Wright Aeronautical Corporation cannot supply this stand but will, upon application, supply the name of the manufacturer and blue prints showing the changes which must be made to adopt it to the "Whirlwind" engine. If one of these is not available a substitute can be made by bolting the iron mounting plate from the shipping box to a suitable wooden stand or the engine can be left mounted in the ship. Disassemble the engine in accordance with the instructions that follow. As each part is removed it should be washed in gasoline and placed on the inspection bench. This should be located near the disassembly floor and where it will receive a good supply of light. A drop light is very handy for inspecting the cylinder bores and valve seats.

A service tool kit shown at Fig. 575 is furnished with each engine by the manufacturer. This contains tools sufficient for the general servicing of the engine and should be carried in the plane for use in emergencies. For completely disassembling and reconditioning the engine, a number of special tools are absolutely essential. These, with others which are not essential but are a great convenience, are shown at Fig. 576. A repair depot handling any great number of engines should be equipped with a complete set. The following instructions for disassembly are presented in as great

detail as space permits. In the event that any point seems obscure, it is suggested that reference be made to the sectional views of the engine at Figs. 561 and 562.

1—Propeller Hub.—To remove the propeller hub use wrenches WA-110 and WA-111 which will be found in the service tool kit accompanying the engine and shown at Fig. 575. After removing the cotter pin, back off the outer or larger nut three full turns. Then back off the inner or smaller nut until it brings up against the outer nut. Holding the inner nut with the wrench as shown at Fig. 578 tighten up on the outer nut until the hub comes loose. It can then be pulled off by backing off on the inner nut. After removing the hub, the inner nut should be replaced on the crankshaft to avoid the possibility of damaging the threads. In loosening the nuts and the hub, it will be necessary to use considerable force—three or four blows with a lead hammer are usually required as at Fig. 577.

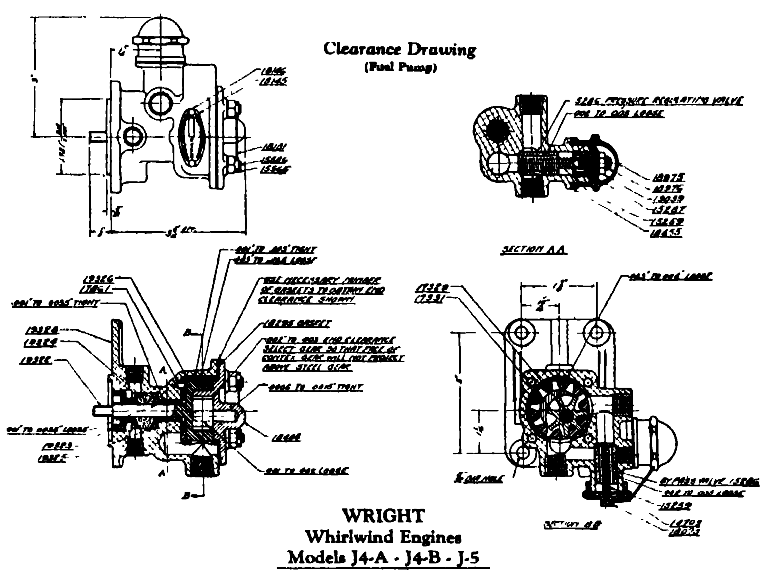


Fig. 569.—Fuel Pump Construction and Clearances of "Whirlwind" Engines Models J4A, J4B and J5.

2—Ignition System.—After removing the wire terminals from the spark-plugs, loosen the clips on the push rod housings and intake pipes and free the ignition wires. It is not necessary to remove the clips. Remove nuts holding the wire manifold to the intermediate section. Remove the oil drain pipe running from the intermediate section to the oil sump. Disconnect the magneto advance rods by unscrewing pin from magneto advance lever. Withdraw the magneto coupling cotter pin and disengage the coupling. Take out the four screws holding each magneto to the bracket. Free magneto from dowels by striking lightly with the hand. Lift off magneto and ignition wiring assembly complete.

3—Carburetor.—If it has not already been done, remove the pipe running from the oil sump to the oil pump and the main fuel line. Remove twelve nuts holding manifold to crankcase and withdraw carburetor and manifold.

4—Priming Lines.—The priming lines should be taken off by removing the stuffing nuts on the various fittings.

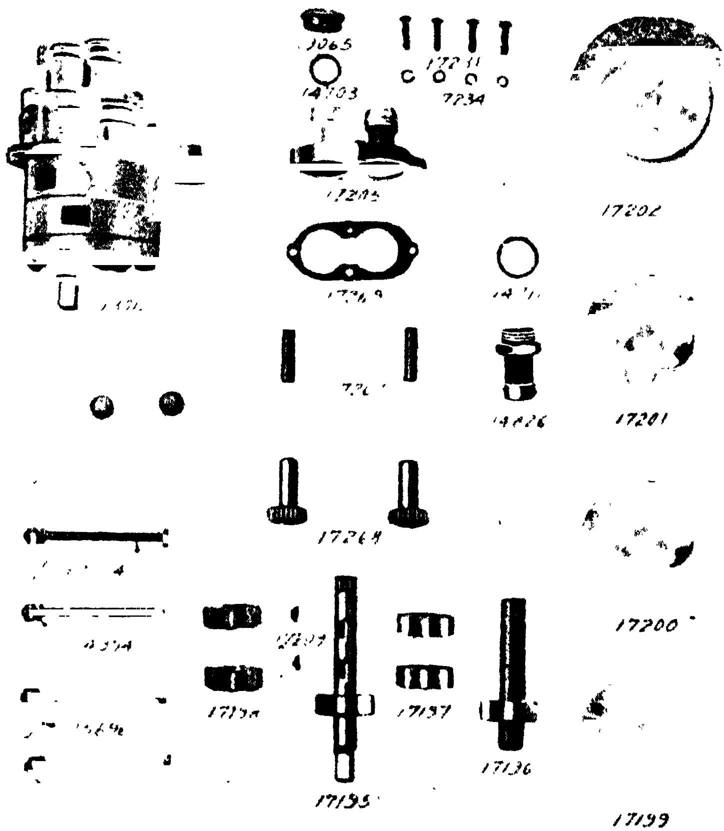


Fig. 570.—Parts of Oil Pump of Wright J5 Aviation Engine.

5—Cylinders.—When an engine is to be given a complete tear down the following rule should be strictly adhered to:—**The No. 1 cylinder should be removed last. Failure to do this and lack of proper care will result in broken piston rings, broken pistons and possibly injured cylinders.** The reasons for this warning and the proper precautions when it is necessary to make an exception to the rule are discussed later in this section. The aluminum plugs in the "Whirlwind" and "Cyclone" engine knuckle pins are a press fit in the pin and should not be removed unless absolutely necessary. **It is necessary to use a new part in replacing the plug in order to obtain the required tight fit.**

Whirlwind J5 Cylinders.—Remove all sparkplugs and rotate the crankshaft until the piston of the cylinder to be removed is approximately on top center. Remove the three screws holding the intake pipe flanges together, loosen the intake pipe packing nut in the crankcase (use tool WA-225) shown at Fig. 576 and remove the intake pipe. Remove two nuts holding down the push rod housing packing flange, lock nuts and cylinder hold-down flange nuts. Rock the cylinder gently from side to side and remove by pulling straight outwards. Be careful that the piston does not swing over against either of the adjacent cylinders and that the push rods

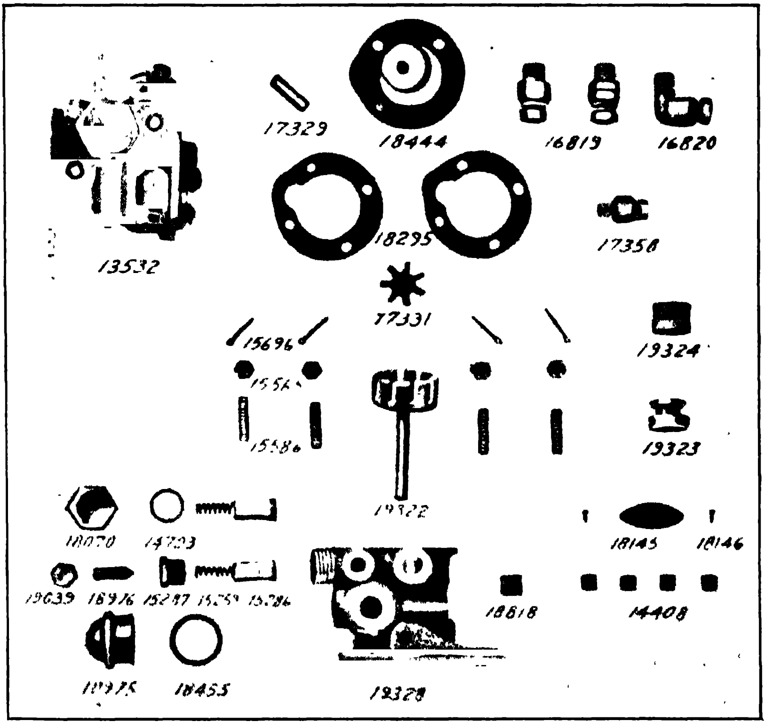


Fig. 571.—Wright J5 Fuel Pump Disassembled to Show Construction of Parts. Compare this with Assembly Drawing at Fig. 569.

or rocker arm cups do not fall out of the housings. As soon as a cylinder is removed the piston should also be taken off to avoid injury in subsequent operations. To disassemble the valve gear proceed as follows:—Take out the two screws on top of the rocker arm housing and remove cover. Remove cotter pins and castellated nuts from rocker arm pins. These are on the outside ends of the pins. With a fiber or brass drift, tap the pins out of the housing towards the center of the cylinder.

For removing the valve springs and washers some sort of a jig to hold the valves in place is handy. This can easily be made from two pieces of wood, one as a base with the other piece (10-inch by 4-inch by 1-inch)

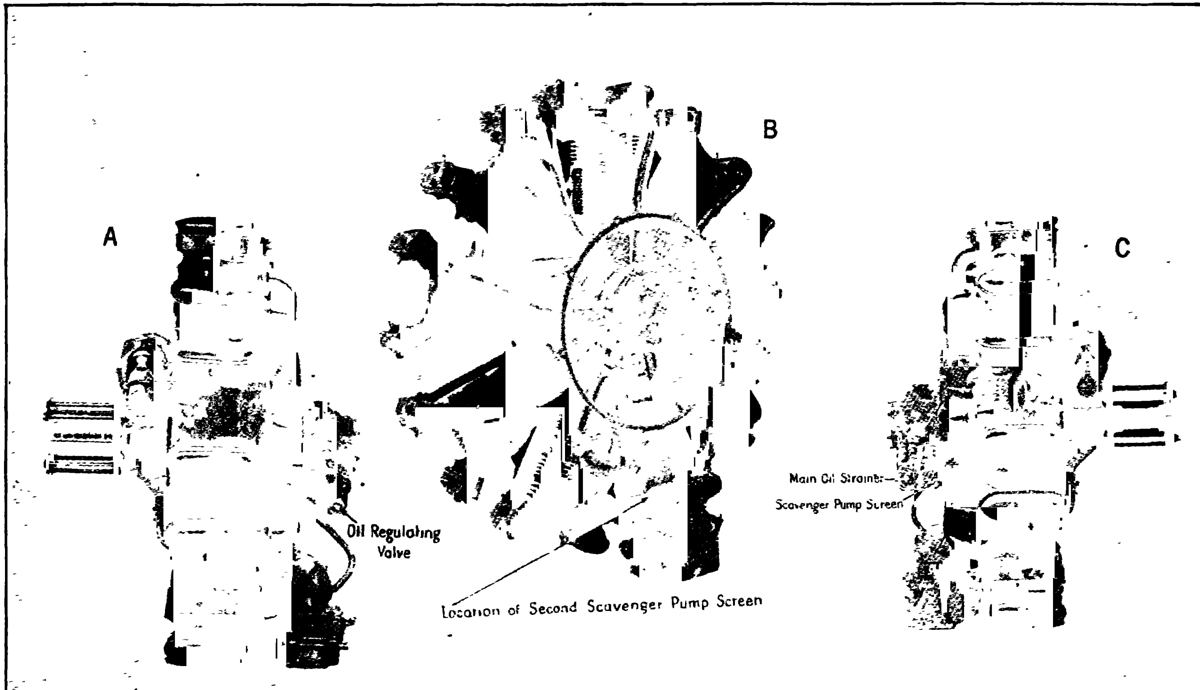


Fig. 572.—Location of Oil Pressure Regulating Valve of Wright J5 Engine Shown at A. Second Scavenger Pump Screen Position Shown at B. Main Oil Strainer and Scavenger Pump Screen Location Shown at C.

nailed to it at right angles. The latter should be trimmed so it will bear lightly on the valve heads when the cylinder is placed on it and the bottom of the sleeve rests on the base. After placing the cylinder on the jig, place valve spring tool WA-226 in position as shown at Fig. 579B and slip a rod through the holes in the housing and the tool. Raising the handle of the tool, depress the valve spring until the split locks can be disengaged. Take off the tool and remove the valve springs and washers. Unscrew the two nuts located inside each rocker box and remove push rod and rocker arm

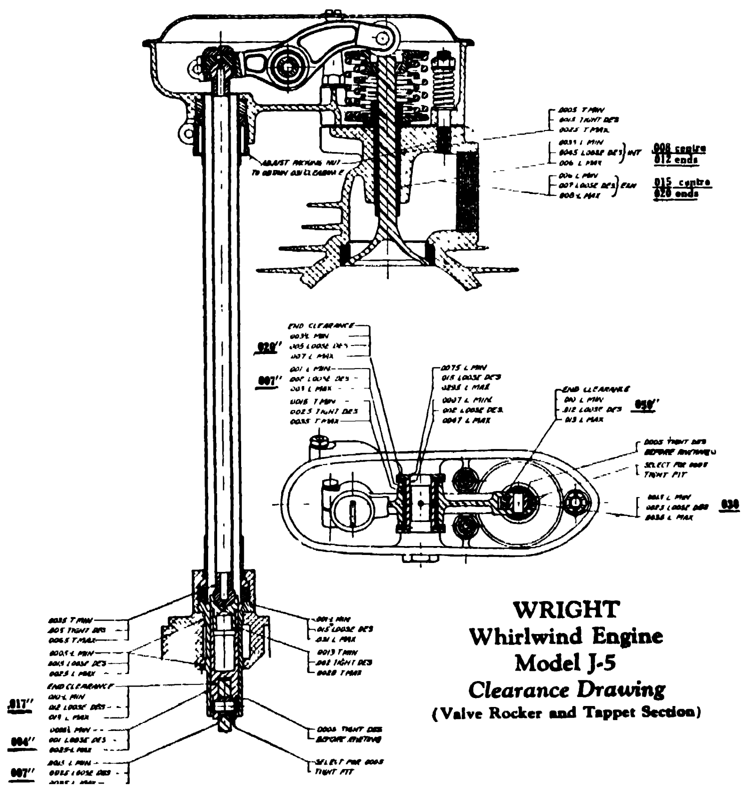


Fig. 573.—Valve Rocker and Tappet Section of Wright Model J5 "Whirlwind" Engine Showing Clearances.

housing assemblies. Do not disconnect the push rod and rocker arm housing assemblies unless necessary. Take off the wire lock rings located near the top of each valve stem. Holding the valves with one hand take the cylinder off the jig and place it in a horizontal position on a bench. Remove valves, taking care that they do not strike the cylinder walls on the way out.

Whirlwind J4A and J4B.—The order of procedure in taking off the cylinders of the Models J4A and J4B is the same, but there is considerable difference in the detail. After removing the sparkplugs and taking off the

intake pipes, the next step is to remove the push rods. This is best done by setting a monkey wrench to the proper size to slip over the rocker arm and with this to compress the valve spring. The push rod can then be lifted out. A convenient method of removing the rods is to first perform the operation on the cylinder which is on the compression stroke and then, rotating the crankshaft, follow the firing order (1, 3, 5, 7, 9, 2, 4, 6, 8) around the engine.

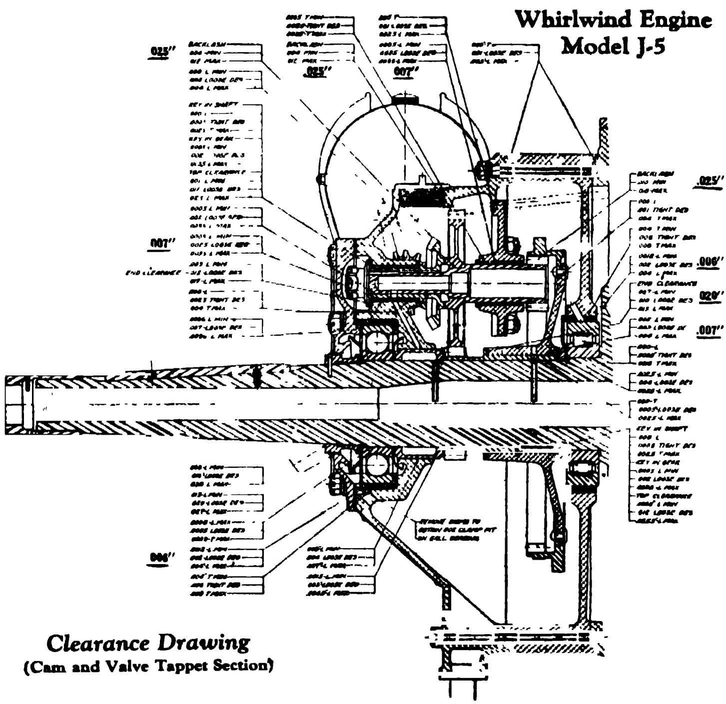


Fig. 574.—Clearance Drawing of Cam and Valve Tappet Lower Section of Model J5 Engine.

The cylinders can then be removed, proceeding as with the Model J5. In disassembling the valve gear the same sort of jig described for the Model J5 and shown at Fig. 579A is necessary. Place the cylinder on the jig and insert the slotted end of tool WA-79 under the shoulders of the rocker arm support. When the other end is pressed down, the end of the valve will project up through the round hole in the tool and the locks can be removed. Proceed as before in removing washers, springs, lock wires and valves.

If the wristpins are a drive fit when cold they should not be removed until the piston has been heated with hot water or steam. They can then be driven out with a fiber drift. Failure to heat the piston first may result in serious injury to the piston bosses and the wristpin plugs.

To Remove the No. 1 or Top Cylinder without first removing the other cylinders proceed as follows:—Set the No. 1 piston on top dead center. Remove the intake pipe, the two nuts holding down the push rod packing flange and the cylinder hold down nuts. Loosen the cylinder by rocking gently back and forth and pull straight out. As soon as it is clear of the studs slip the two rods WA-281 into place between the master rod and the crankcase studs, one on either side. This will prevent the rod from tipping sideways and consequently keep the bottom rings on the No. 5 and No. 6 pistons from coming up over the ends of the cylinder sleeves and breaking. The cylinder should be removed very carefully with a straight, steady pull. The re-assembly should be performed in the reverse order.

6—Nose Plate.—To remove the nose plate, take off the lock wire and with a spanner wrench unscrew the thrust bearing nut. Then remove the nuts and washers and pull off the nose plate.

7—Crankcase Front Section.—The studs in the front of the J5 crankcase main section extend through the intermediate and front sections holding the three together, while two sets of short studs perform the same function on the J4B. Remove the nuts and pull off the front section. The front thrust bearing and the spacer on the crankshaft will come off with it. The section can be loosened by tapping lightly on the lower corners of the magneto brackets with a lead hammer. The cam drive gear should then be removed This is keyed to the crankshaft and should be pulled off with tool WA-231 shown at Fig. 576. The cam, cam spacer and oil slinger can then be lifted off.

8—Intermediate Section—After removing the nuts (J4B), reach inside the crankcase with the lead hammer and tap lightly on the bottom of the intermediate section. This section can then be freed from the main section and the roller bearing.

9—Connecting Rods.—Cut all the lock wires and remove the cap screws and knuckle pin locks. Using tool WA-92 as shown at Fig. 580 pull out the knuckle pins, removing each rod from the engine as its pin is withdrawn. In using this tool first run the nut out to the head of the bolt and then screw the bolt down into the pin at least six full turns. Failure to do this may result in stripping the threads inside the pin. Run the loose nut down until it seats on the puller body and turn up on it with a wrench, withdrawing the pin.

10—Master Rod.—With the long handled socket wrench (WA-189) used as shown at Fig. 581 take out the four master rod clamping screws. Tap on the master rod until the two parts separate and can be removed.

11—Crankshaft.—Do not under any circumstances remove the crankshaft counterweights. If this is necessary the crankshaft should be returned to the factory where the assembly can be properly balanced before using again. Turn the motor over until the crankshaft is in a horizontal position and proceed as follows:—Unscrew nuts and remove starter. With a screwdriver take out the screw which will be observed in the center of the starter dog. Pull out the starter dog. Pull out the accessories drive gear using tool WA-169. The crankshaft will then be free and should be removed by pulling straight out through the front of the crankcase.

Take off the nuts holding the rear section to the crankcase, not for-

getting the one at the bottom behind the oil strainer, and remove the rear section. Remove four nuts and pull off fuel pump. Remove four nuts and pull off oil pump. Remove four nuts on each and pull out the gun synchronizers. To disassemble the fuel pump remove the four castellated nuts and take off the cover. The two gears can then be removed and inspected for wear. Remove the two valves and see that the seats are in good condition. The photograph at Fig. 571 shows a fuel pump disassembled. To disassemble the oil pump remove the four long bolts holding the four sections together. Remove the four screws holding the tachometer drive housing to the oil pump cover. Examine all gears and housings for wear. The photograph at Fig. 570 shows an oil pump disassembled.

Inspection.—When the disassembly is complete and all the parts have been washed and laid on the bench a very careful inspection should be made. This should consist of a general examination for signs of wear or failure and a check of all wearing parts against the clearance diagrams shown at Figs. 584, 585 and 586. The question of when a part should be replaced is one which cannot be decided by rule and must be left largely to the judgment of the inspector. As a guide in this work a list of the maximum allowable clearances for all wearing parts is given in underlined figures on the clearance diagrams. These figures represent the greatest amount of looseness allowable before a given part should be replaced. This should not be construed to mean that any parts showing less wear are satisfactory, as the appearance very often has more to do with a part's condition than the actual dimension. They are suggested as guides where looseness is the only consideration. When clearances are found to be in excess of those noted by the underlining an investigation should immediately be started to determine the cause which is very often traceable to wear or failure of some other part. The piston rings should be checked for tension by measuring the gap between two corresponding points on the ends when the ring is free. If this is less than ¼-inch the ring should be replaced.

The crankshaft main bearings and thrust bearing should be very carefully inspected for wear or deterioration. Clean each bearing thoroughly in gasoline and spin it, listening for any sound indicating uneven running. Hold the inner race in one hand and rotate the outer race slowly with the other. As each ball passes, inspect for cracking, chipping or corrosion. The same inspection should be made on the races. It is very difficult to make a good inspection of a roller bearing—the inspector should be guided largely by the smoothness of rotation and the amount of play. Roller bearings are built with some end play but should have very little radial play. Any bearing which is chipped, cracked or corroded, or which is excessively loose should be discarded.

If it is necessary to replace the master rod main bearing or any of the articulated rod bearings it is of the greatest importance that the reaming be done accurately and the proper alignment obtained. This necessitates the use of master and articulated rod reaming fixture WA-224. If this tool is not available the rod should be returned to the manufacturer for replacement of the part.

The sparkplugs should all be taken apart and cleaned. Emery is a

good conductor of electricity, so emery cloth should never be used for this purpose. Use garnet cloth, sandpaper or a steel scraper. Set the gaps to .015-inch. (B. G. plugs) by tapping on the outside end of the outer electrode with a center punch and hammer. If A. C. plugs are being used they should be washed in gas, cleaned in an air blast and have the gaps set at .020-inch to .025-inch.

Inspect the sparkplug threads in J5 cylinders for signs of wear or picking up. The bronze bushings were omitted in this design with the idea of improving the running conditions of the sparkplugs and the tapped hole in the head substituted. Care must be taken in inserting and removing sparkplugs to prevent stripping the aluminum threads. The plugs should be selected for smoothness and proper fit of the threads and no plug which will not go in without undue forcing should be used.

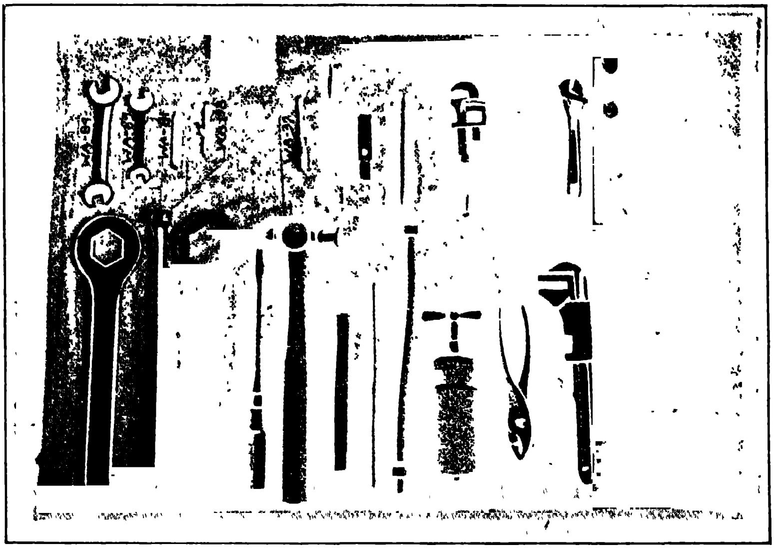


Fig. 575.—Service Tool Kit Used for Top Overhaul of Wright "Whirlwind" Engines.

The fuel pump should be disassembled and inspected for wear. The maximum allowable clearances which are shown at Fig. 569 are as follows:

Internal gear shaft in bearing	.006″
Internal gear in housing	.008″
Contex gear on pin	.004″
Contex gear to cover	.004″

Remove the valves and see that the seats are in good condition. Lap if necessary. Inspect the packing on the shaft and replace if not in good condition. Any gas leaking past this goes into the crankcase and dilutes the oil. The Contex gear should not project above the end of the internal gear. Adjustment to the desired end clearance of .002-inch to .004-inch can be made by varying the thickness of the cover gasket or, if necessary, by

grinding either of the two gears.

If their condition warrants it, the cylinder valve seats should be cut, using the tools listed for that purpose, and the valves faced off in a grinder. They should then be ground and tested for tightness with gasoline. The type of stand illustrated at Figs. 587, 588 and 589 are very convenient.

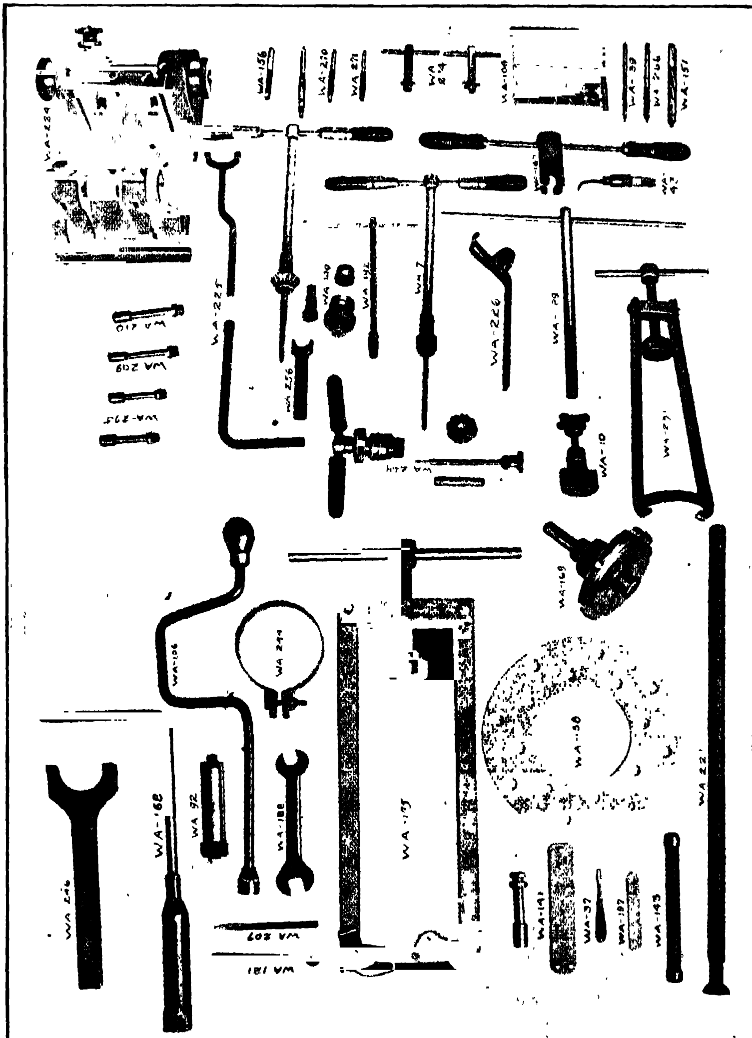


Fig. 576.—Repair Depot or Special Tools Used in Overhauling Wright "Whirlwind" Engines.

Replacement of Valve Guides.—If the valve guides in a cylinder become worn, allowing clearances in excess of those noted in underlined figures on the clearance chart Fig. 573 it is advisable to replace them with new parts. By so doing the valves are held straight on their seats and loss of compression, leaks and burned valves are avoided. The intake and exhaust valve

guides on Model J4A and J4B engines and the intake valve guides on the Model J5 engine are of bronze, necessitating the use of counterbores in removing them. Set the cylinder up in a suitable machine and run the counterbore through the guide, the pilot centering the tool and preventing injury to the cylinder. This leaves a shell $\frac{1}{64}$-inch thick which can be removed with cape chisel WA-207. Attempts to drive the guides out with a drift are very liable to end in their seizure in the bosses necessitating replacement with oversized parts. The J5 exhaust valve guide is of hardened tungsten steel and can be pulled out without danger of seizure. The guide boss should first be heated for several minutes with a blow torch applied through the valve port. Then puller WA-273 should be put on and the guide removed.

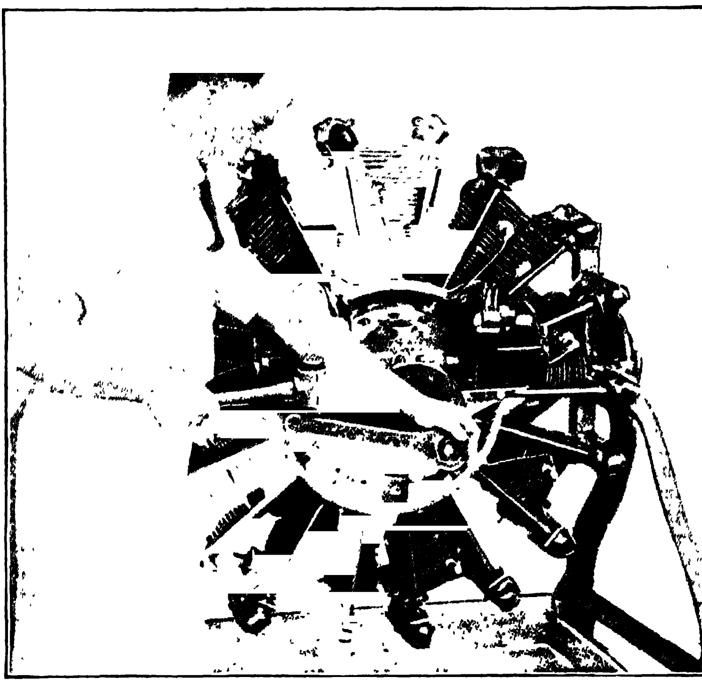


Fig. 577.—Removing Propeller Hub, Model J5 Engine, First Operation; Using Special Tool WA-111.

Method of Replacing Guides, J4A, J4B and J5.—(a) Inspect the hole from which the guide has been removed and measure its diameter with inside calipers and a micrometer. The hole should be from .001-inch to .002-inch smaller than the guide which is used for replacement. It will usually be found possible to use standard guides for replacement, but if the hole is found to be mutilated or less than .001-inch below the O. D. of the guide, an oversize replacement guide will be necessary. (b) If it is found necessary to use an oversize replacement guide, the cylinder guide hole should be reamed to a diameter from .001-inch to .002-inch less than the outside

diameter of the guide. In other words, a drive fit of from .001-inch to .002-inch is desired. The reaming operations should be carefully done using the reamer pilot bushing WA-283, as it is absolutely necessary to hold to these limits. A tighter fit may break the cylinder and a looser fit may allow the guide to come loose in service. (c) Insert in the new guide the special drift provided (see list below) and tighten drift nut. (d) The valve guide bosses should be heated with a blow torch before driving in the guides. (e) With a wooden or rawhide mallet, drive home the guide until shoulder seats firmly on cylinder. Remove drift. (f) Ream inside diameter of guide with finish reamer to give a clearance of .002-inch to .003-inch over the inlet valve stem and from .003-inch to .005-inch over the exhaust valve stem on J4A and J4B engines. (g) The J5 intake valve guide should be reamed to a clearance over the valve stem of .004-inch to .006-inch. (h) The J5 exhaust valve guide is ground to size at the factory. The reaming operation is unnecessary as the guide will not contract when inserted in the cylinder.

A complete list of tools for the operation follows:

TOOLS FOR REMOVING AND REPLACING VALVE GUIDES IN J4A, J4B AND J5 CYLINDERS

J4A and J4B	
Intake guide counterbore	WA-201
Exhaust guide counterbore	WA-202
Cylinder Reamer intake and exhaust .005" oversize	WA-205
Cylinder Reamer intake and exhaust .010" oversize	WA-206
Inserting drift intake	WA-209
Inserting drift exhaust	WA-210
Guide reamer intake	WA-218
Guide reamer exhaust	WA-219
Exhaust guide puller	WA-273
Intake guide counterbore	WA-272
Cape chisel with $\frac{1}{16}$" blade	WA-207
Cylinder reamer intake .005" oversize	WA-203
Cylinder reamer exhaust .005" oversize	WA-205
Cylinder reamer intake .010" oversize	WA-204
Cylinder reamer exhaust .010" oversize	WA-206
Pilot bushing for reamers	WA-283
Inserting drift intake	WA-275
Inserting drift exhaust	WA-282
Guide reamer intake	WA-266
Valve guides J4A and J4B	
Intake standard size	18176
Exhaust standard size	18177
Valve guides J5	
Intake, Standard Size	19362
Exhaust, Standard Size	19363

Note:—When ordering oversize valve guides specify size required.

Check the thickness of the metal above the J4 series rocker arm ball cups and replace if this is less than $\frac{5}{64}$-inch (.078-inch). An easy way to make the measurement is to set a pair of outside calipers at $\frac{1}{2}$-inch (.500-inch) and with one point located in the bottom of the cup to measure the distance from the outside of the rocker arm to the other point with a scale. The desired dimension can then be obtained by subtraction. Inspect each

push rod ball end for roundness and for signs of contact with the rocker on the ball neck. If the rocker has been hitting, the ball end should be replaced.

Assembly.—The successful operation of the engine is absolutely dependent on the attention given to every detail in inspection and assembly.

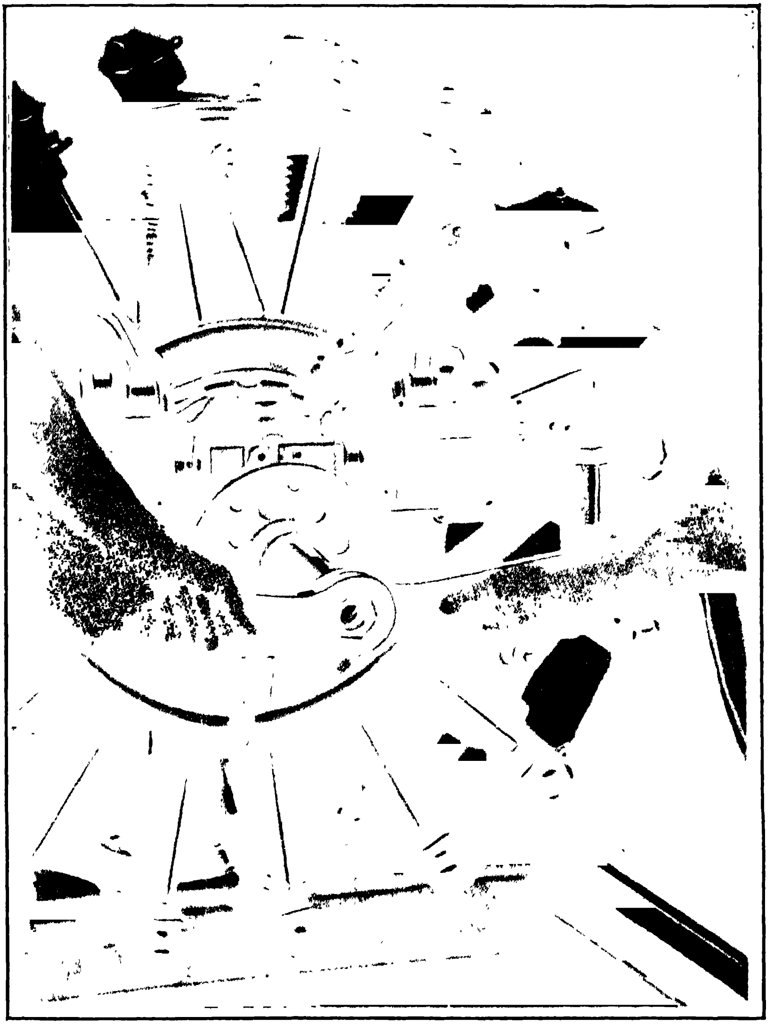


Fig. 578.—Third Operation in Removing Model J5 Propeller Hub Using Tools WA-110 and WA-111.

It should be constantly borne in mind that the slightest neglect on the part of inspector or mechanic may result in the failure of the engine and the possible loss of one or more lives. Cotter pins and lock wires which have been badly bent should never be used again. Great care should be

taken to prevent dirt, dust, cotter pins, lock wires, nuts, washers and other small parts from falling into the inside of the engine. These might work into the gears or oil lines and cause immeasurable damage. If the engine is to stand for any length of time before being used, all steel parts, both inside and outside, should be covered with oil to prevent rust. Completely finish each step in the process of assembling as the work progresses. Do not leave a bolt loose or a nut not cottered with the idea of coming back to it later on. Never slack off on a nut in order to line up the notch in the nut with the cotter pin hole in the bolt or stud. If it cannot be tightened sufficiently with reasonable effort replace it with another nut.

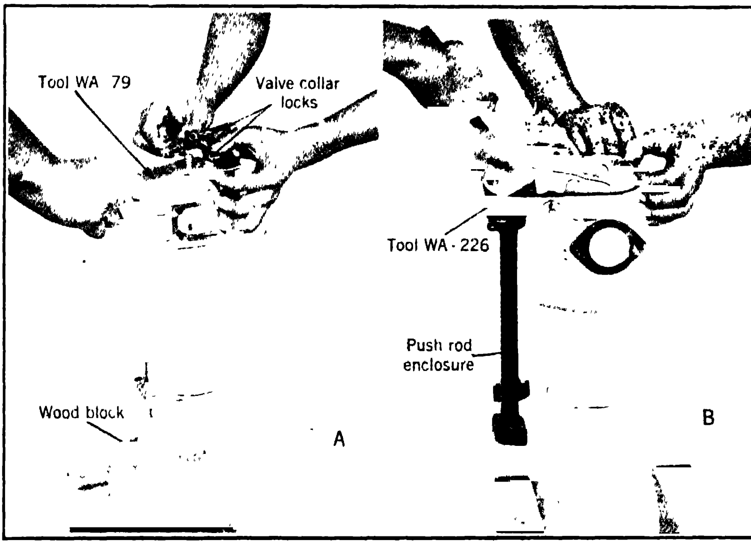


Fig. 579.—Method of Removing Valve Collar Locks of Model J4B Engine with Tool WA-79 Shown at A. Removing Collar Locks of Model J5 with Tool WA-226 Shown at B.

Before assembling in the engine, all parts should be thoroughly cleansed and made free from grit. Wipe with a clean dry rag which is free from lint. Do not use waste or tattered rags, pieces of which might be left unnoticed inside the engine and clog up pipes or strainers. Remember that the engine will turn over a number of times before the oil pump will start to furnish the regular supply of oil, therefore coat all bearing surfaces with a good supply of standard engine oil before assembling. All studs, nuts and parts which are a drive fit should likewise be oiled. In the assembly procedure following it will be assumed that this has been done where necessary. In places where there is the possibility of oil leaking out between two machined surfaces, as under the cylinder hold-down flanges, it is recommended that the surfaces be coated with soft soap before assembling. This should be of good quality and free from lumps or foreign matter. Murphy's Oil Soap manufactured by Phoenix Oil Co., Cleveland, Ohio, has been found very satisfactory for this purpose. Soap

presents many advantages over the compounds most generally used for sealing and is highly recommended.

For convenience in assembling the engine a list of the various parts and the location of their identification numbers is given below.

Cylinders.—The engine number and the cylinder number are stamped on the cylinder head over the intake port.

Valves.—The cylinder number is etched on the upper side of the valve head.

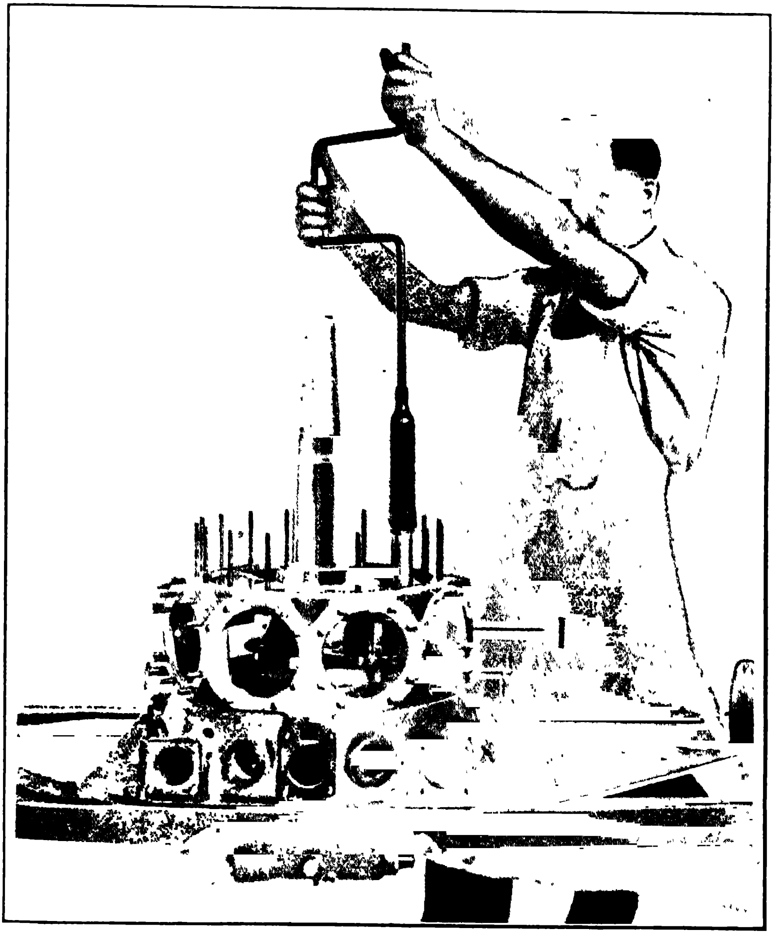


Fig. 580.—Removing Wright J5 Knuckle Pins Using Tools WA-92 and WA-168.

Rocker Boxes.—The cylinder number is stamped over the rocker arm pin boss.

Crankcase.—The engine number is stamped on the side of the No. 1 cylinder pad and the cylinder number is stamped on the front side of each pad.

Crankshaft.—The engine number is stamped in the aluminum plug in the front end.

Master Rod.—The engine number is stamped on top of the front flange. The four clamping bolts are numbered and corresponding numbers are stamped at the top ends of the four holes.

Pistons.—The cylinder number is stamped on the top of each piston towards the front of the engine, and the engine number is on the opposite side.

Link Rods.—The link rods bear the engine and cylinder numbers on the front side near the piston end.

Wristpins.—The cylinder number is stamped on end plug in each wristpin.

Knuckle Pins.—The cylinder number is etched on the top of each knuckle pin.

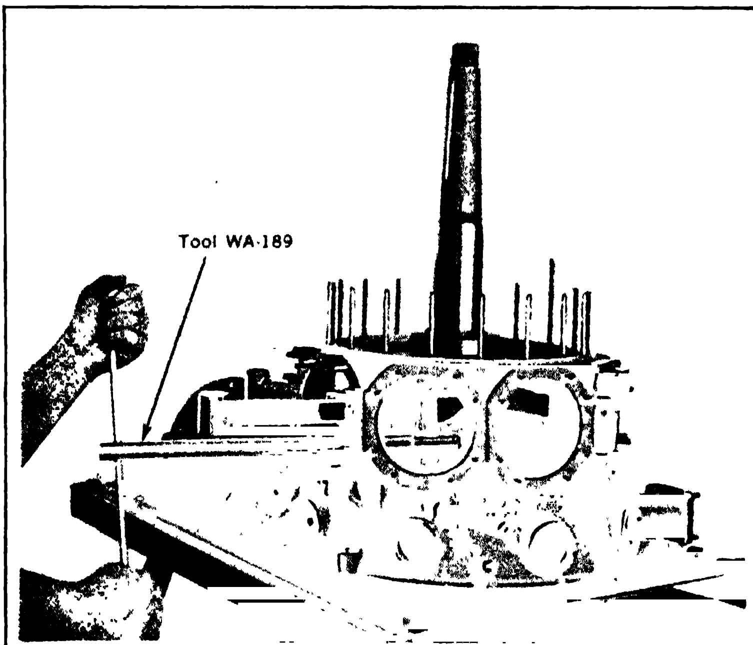


Fig. 581.—Removing Master Rod Bolts of Model J5 Using Tool WA-189.

1—Crankcase.—After cleaning the crankcase, bolt it securely to the assembly stand by at least four good bolts.

2—Crankshaft.—If the crankshaft main bearings have been removed they should be replaced in their original positions. The manufacturer's names and numbers face the ends of the shaft. The retaining nut on the rear end of the shaft should be run up against the bearing and the slinger until it is in its original position as shown by the center punch mark on the shaft and the lock wire hole in the nut. The lock wire should then be replaced. Any plugs which have been removed for cleaning the shaft

should be replaced and locked in place with a center punch. The roller bearings should then be filled with vaseline and the crankshaft inserted in place in the crankcase.

3—Connecting Rods.—Tilt the stand so the crankshaft is in a vertical position. The two halves of the master-rod bearing should then be put back in their places in the two parts of the rod and the babbitted surfaces coated with oil. The crankpin should also be oiled. Place the upper part of the master rod in position with the shank protruding from the No. 1 or top cylinder opening. Place the lower part of the rod in position, making sure the knuckle pin lock plate screw holes are facing up. Replace the

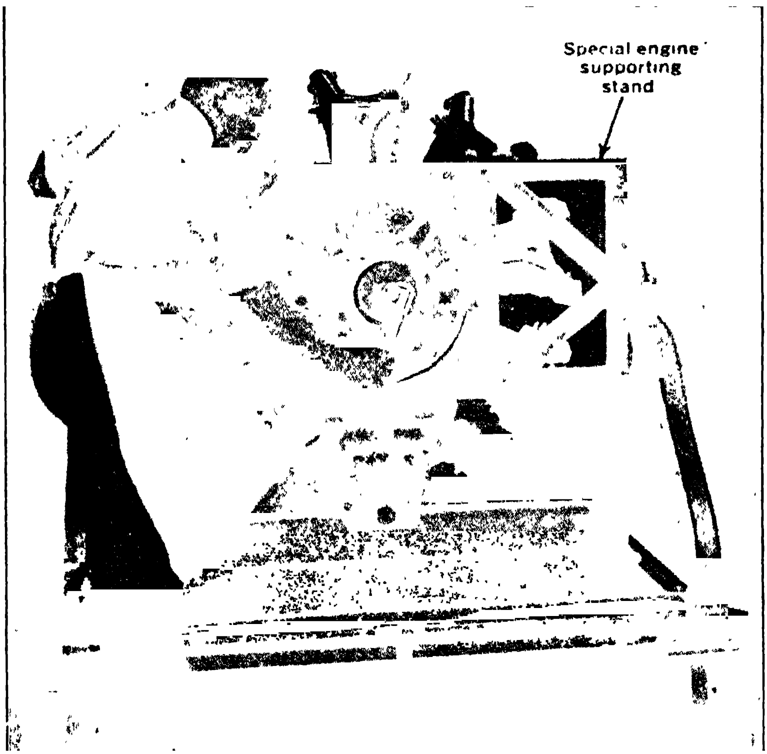


Fig. 582.—Removing Crankshaft Gear of Wright Model J5 Using Tools WA-169 and WA-132.

four clamping screws in their proper places according to the numbers on the screws and the rod and turn up with socket wrench WA-189 until the numbers on the screw heads correspond with those on the master rod when set up tightly. It is best to first tighten up all the screws until they are quite snug and then to bring them all up to their proper positions, a few degrees at a time. This insures a uniform set of the two halves and avoids the application of unnecessary strains. The bottom, or rear, screws should be wired using the two small holes provided in the rear flange of the rod.

It is of the greatest importance that this be done and done well.

The link rods should then be put in. Coat the bushing in the rod and the knuckle pin with oil and slip the rod into place with the number up. Thrust the knuckle pin into position as far as it will go by hand and then tap down with a block of fiber or hard wood. The straight side of the pin top should be facing the lock plate screw hole. If it does not seem to be in alignment after assembly it can be turned by carefully using a brass drift on one side or the other. The rods should all be put in in this fashion and the pins locked in place with the locking plates and screws. The two lower screws should then be wired together and each of the upper screws should be wired to the nearer master rod clamp screw.

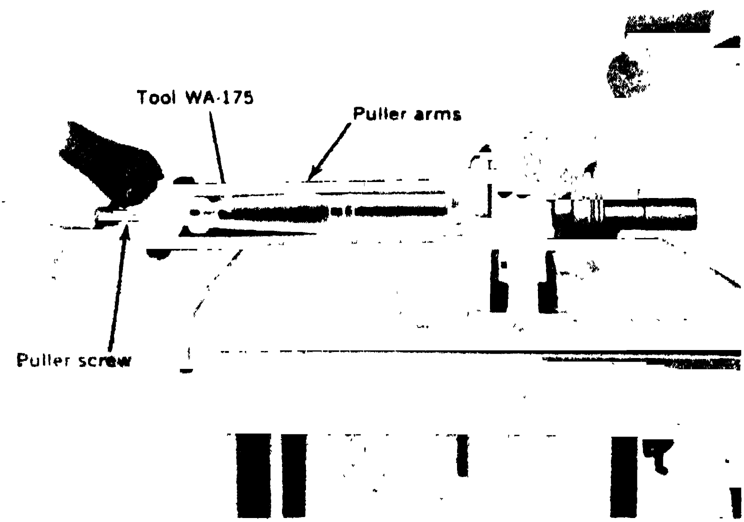


Fig. 583.—Removing Crankshaft Main Bearing of Model J5 Engine Using Tool WA-175.

4—Intermediate Section.—The intermediate section should then be put in position and tapped down over the front crankshaft roller bearing. A dowel in the face of the main crankcase permits the intermediate section to be put on in none but the correct position. The oil slinger, the small steel spacing ring, and the cam should next be slid on over the crankshaft in the order named. The internal gear on the cam faces the front of the engine. The cam drive gear, well oiled, is then tapped into place, the cam bearing sliding inside the cam hub and locating itself on the key in the crankshaft.

5—Front Section.—If the cam and magneto drive shaft has been removed from the front section it should then be replaced. The front section should be assembled in place with the long crankcase stud extending through the oil drain pipe boss at the bottom (J5). On J4A and J4B engines the oil drain pipe is connected at the bottom of the intermediate

section. Put washers and castellated nuts on crankcase studs and draw up tight. Lock with one wire running all the way around the case. Slip the crankshaft spacer and the thrust bearing rear oil slinger into place. On J4A and J4B engines this slinger is almost flat, while on the J5 it is spun over in an arc of almost 90 degrees. The front slinger is the same in all models. Fill the thrust bearing with vaseline and tap into place. Put on the thrust bearing front oil slinger and the crankshaft nut. Tighten the nut until the crankshaft has been pulled up into position and the center punch mark on the crankshaft comes opposite the locking wire hole on the nut. Use tool WA-246.

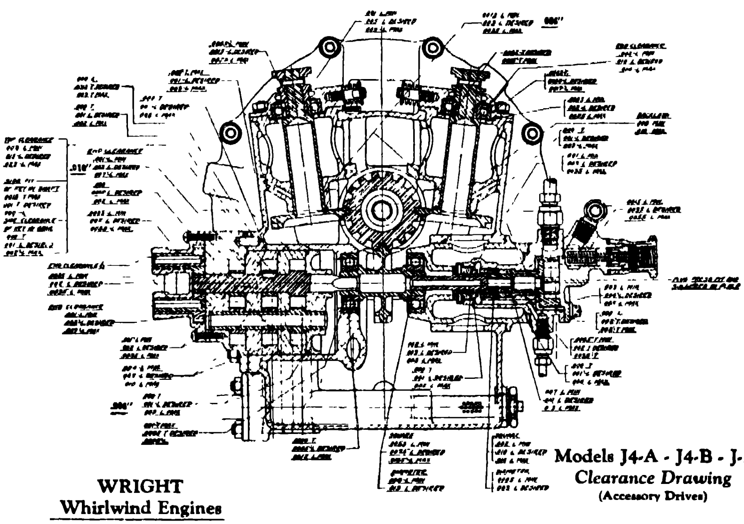


Fig. 584.—Accessory Drives of Models J4A, J4B and J5 Wright Aviation Engines Showing Clearances.

6—Pistons and Cylinders.—In replacing the pistons and cylinders, always put on the No 1 piston and cylinder first. Cylinders of Model J4A and J4B engines should be assembled complete with valves, springs and rocker arms before putting them on the engine. Model J5 cylinders should have only the valves, springs and washers, leaving the valve operating gear until later. If the wristpins are a tight fit the pistons should be heated before they are put on the engine. This can be done with hot water or in a small oven of some sort. Hold the piston in position and push the wristpin into place so the plug ends are flush with the outside of the piston. Apply a liberal coating of oil to the piston and the inside of the cylinder sleeve. Compress the piston rings with ring clamp WA-244 and slide the cylinder over the top rings as shown at Fig. 590. Shift the clamp to the bottom ring and slide the cylinder into its proper position in the crankcase. Secure with the eight hold down nuts and lock nuts.

It is perhaps unnecessary to observe that the cylinder cannot be put

on with the sparkplugs in their bushings. A very convenient and safe system is to have on hand a number of old sparkplug shells which have had bits of 60 mesh screen soldered onto the outer ends. The regular plugs can be put in the rear bushings and these dummies in the front. This prevents dirt and chips from entering the combustion-chambers while the engine is being assembled and still allows the mechanics to rotate the crankshaft freely. Replace the intake pipes as shown at Fig. 591.

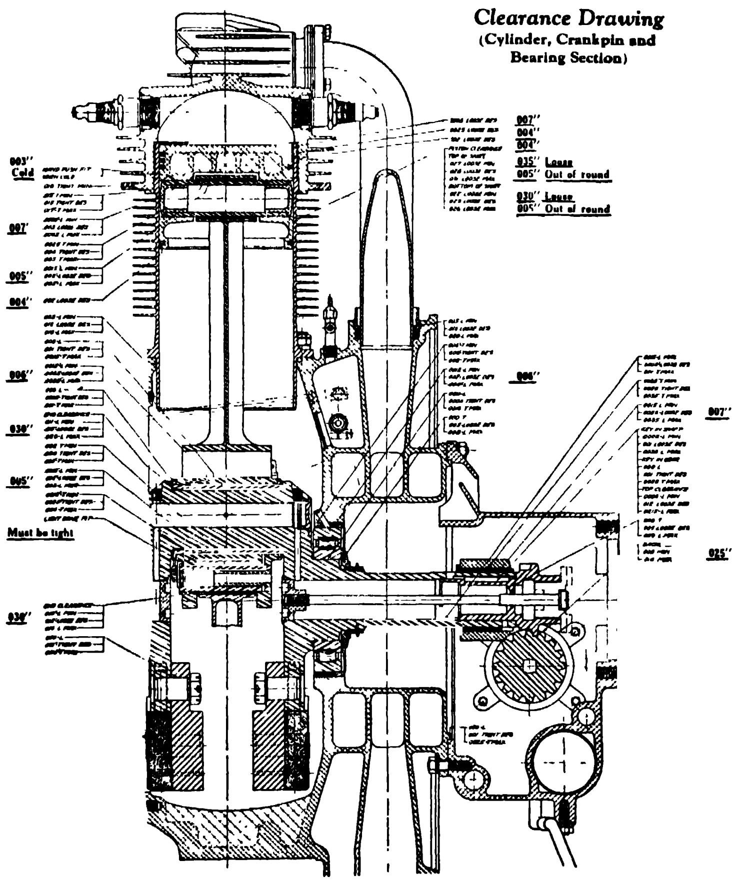


Fig. 585.—Cylinder, Crankpin and Bearing Section of Wright Model J5 Showing Clearances.

7—Valve Operating Mechanism.—On the Models J4A and J4B assembling the valve gear consists in inserting the push rods in position. The inside cam follower (nearer the cylinder) operates the intake valve and the outside follower (towards the propeller) operates the exhaust valve. The J5 assembly is more complicated. The rocker box and push rod housing assembly is put back in position and the nuts and washers are replaced.

Do not forget the spacing washers which go on the two front studs before the rocker boxes are put on. On the early engines it is very easy to confuse these washers (part No. 19,414) with the washers under the nuts holding down the rocker box (part No. 19,413). They can be identified as follows: Part No. 19,414 (under the box) is .031-inch ($\frac{1}{32}$-inch) thick and is ground on both sides, while part No. 19,413 (inside the box) is .047-inch ($\frac{3}{64}$-inch) thick and is not ground. Part No. 19,413 is also used at top and bottom of

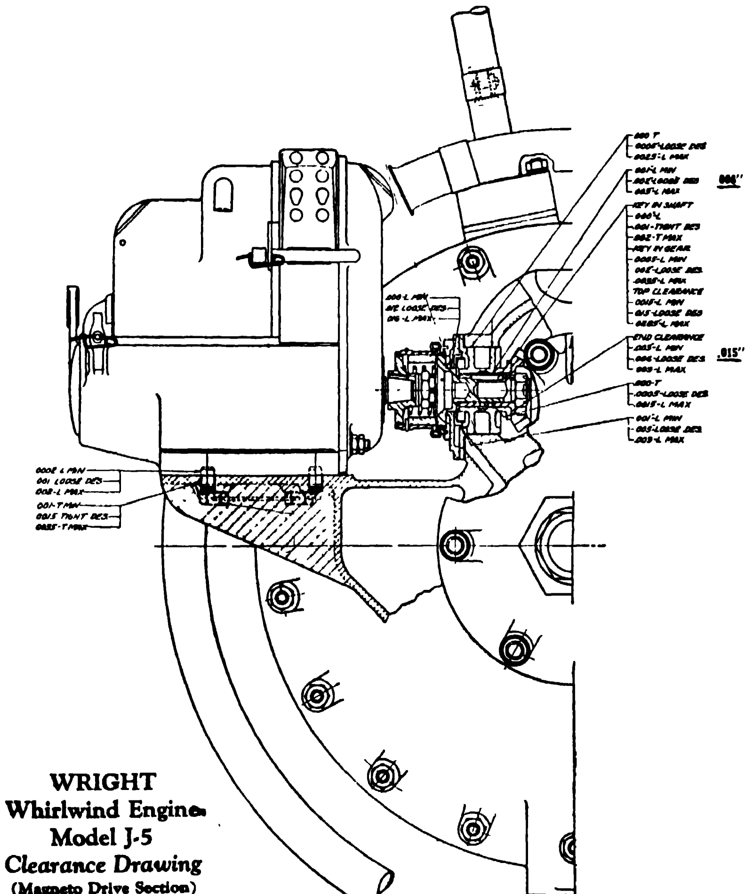


Fig. 586.—Magneto Drive Section of Model J5 Engine Showing Clearances.

the rocker box springs. On the later engines spacer No. 20,313 is used in place of the two washers No. 19,414. The packing nut at the top of the housing should be adjusted to give .031-inch clearance between the rear end of the rocker box and the cylinder pad. The push rod ball ends should then

be dipped in oil (preferably 600W) and the rods inserted in the housing. Then the rocker arms are assembled in place. Be sure the hardened steel push rod ball cup is in place. If the cups are coated with heavy oil on the outside before inserting in the rocker arm they will stick in place and much annoyance will be avoided. The castellated nut which locates the rocker arm pin in the housing should be turned up until it is snug and cotter pinned in place. Be sure this nut is tight as it clamps the thrust washers against the steel bushing on the rocker and insures the proper bearing of the rocker arm.

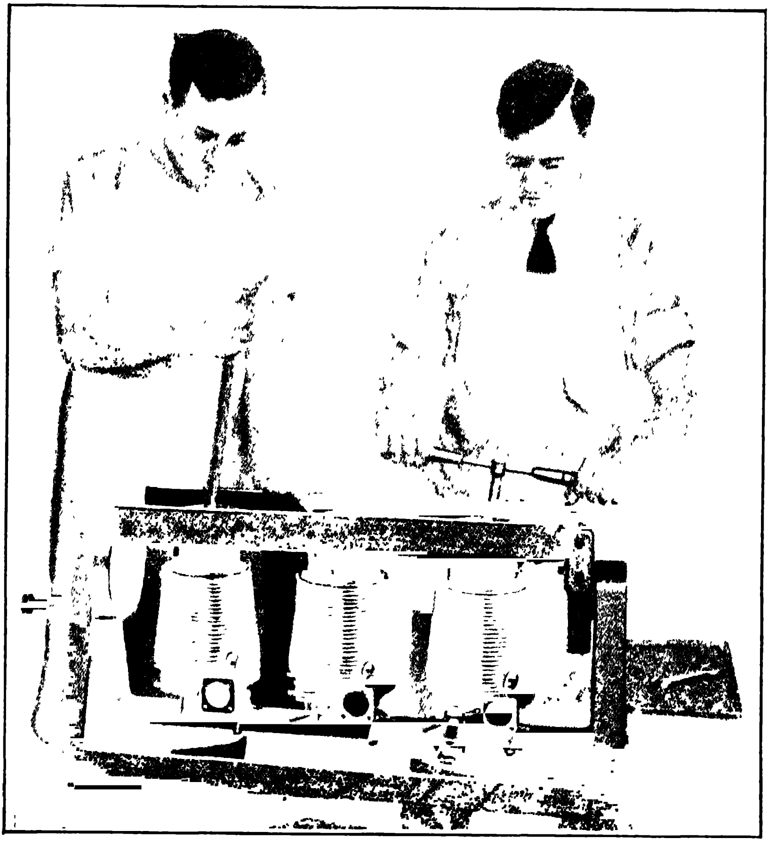


Fig. 587.—Grinding Valves and Cutting Valve Seats of Models J4A and J4B Using Tools WA-221, WA-7 and WA-140.

Inspection and Assembly of Valve Springs.—It has been noted in the factory that in assembly it is possible for the intermediate valve spring to ride on the shoulders of the upper and lower valve washers rather than to slip into place inside. This causes the spring to bottom when the valve is in the full open position and may result in failure of the valve or valve washer. It is essential that all J5 Series engines now in service be checked

for this defect, proceeding as follows:—(a) Remove the rocker box covers and the front set of sparkplugs. (b) Check the tappet clearance in accordance with Service Instruction No. 35. (c) Rotate the propeller until the exhaust valve on No. 1 cylinder opens. Ascertain the opening and closing positions and set the propeller so it is half way between the two. The roller will then be riding on the high point of the cam. (d) Loosen the clamping screw on the end of the rocker arm and turn down on the valve clearance adjusting screw until the springs bottom. Note the number of divisions on the rocker arm which are passed by the arrow on the adjusting screw. (Each division is equivalent to .005-inch motion of the valve).

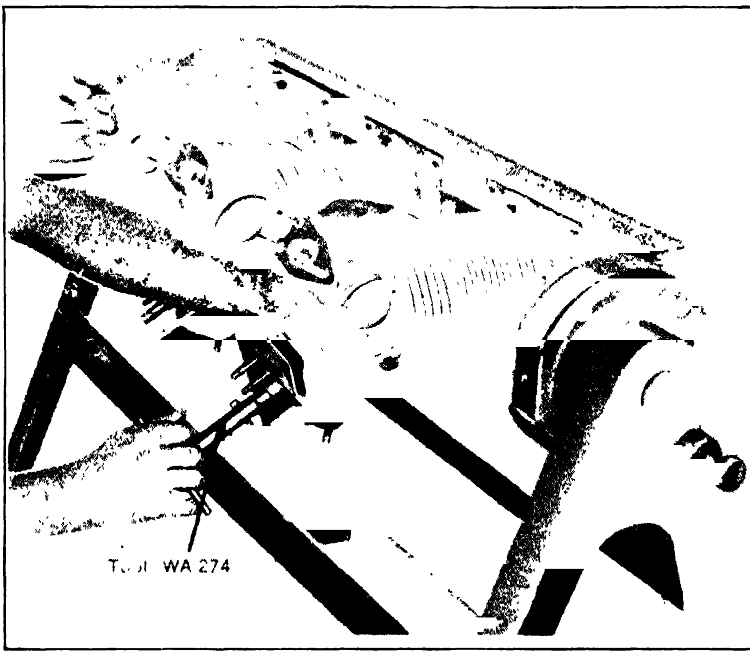


Fig. 588.—Method of Using Tool WA-274 to Grind Model J5 Valves.

(e) The valve will normally move from .060-inch to .070-inch in which case the adjusting screw should be returned to its original position. If it is impossible to turn down on the adjusting screw more than .020-inch the intermediate spring is not in position and should be corrected. (f) This can usually be done by moving the propeller until the valve closes and then working the intermediate spring around with the point of a screwdriver. It will usually snap into place with a very noticeable noise. If it cannot be done in this manner it will be necessary to remove the rocker arm and the upper washer. As soon as the spring is in place, check the valve motion as before. (g) Check the springs on the No. 1 intake valves; then proceed on around the engine, taking the valves in order so none will be missed. (h) Check the tappet clearance in accordance with previous instructions. In assembling an engine after overhaul this should be checked when the

valves and springs are replaced in the cylinders. With no rocker boxes to interfere it is quite easy to thrust the point of a screwdriver under the top or bottom of the outer spring and obtain a good view of the intermediate spring.

Valve Operating Mechanism Adjustments.—Reports from the field seem to indicate that the operation and maintenance of the valve gear on the J5 Series "Whirlwind" engines is not thoroughly understood. Furthermore, since a number of engines of this series have been in service for a considerable time, additional points of interest relative to upkeep have been brought out. Consequently it has been found advisable to issue this service

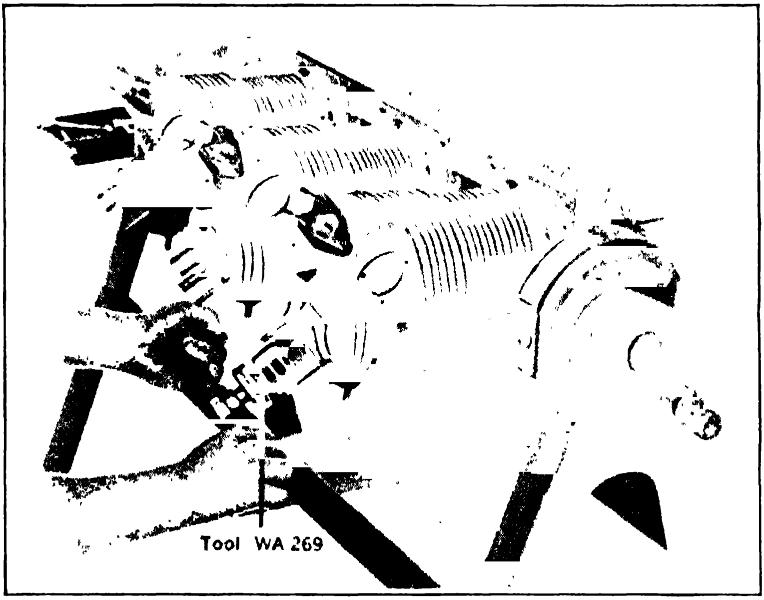


Fig. 589.—Method of Using Tool WA-269 for Cutting Valve Seats of Wright Model J5 Cylinder.

instruction to bring up to date information for maintenance found in the manual. The following routine is suggested for checking the valve gear. This should be done on one cylinder at a time following the method outlined in Instructions to follow.

1. After the engine has been in service for twenty hours loosen the push rod housing clamping screw and back off on the adjusting nut until the push rod housing is free. With a set of thickness gauges check the clearance under rear end of the rocker box. To this value add .005-inch and tighten up on the adjusting nut until the increased clearance is obtained. Then tighten up on the clamping screw. It is essential that this be done when both the valves are closed to prevent errors caused by the forces set up when the valve is opening or closing.

2. Check the valve tappet clearances in the manner prescribed. Just before checking the clearance, the push rod end of each rocker arm should

be tapped sharply with a hammer handle to make sure the roller is riding on the cam. The cam followers are fitted with very little clearance and are sometimes too tight to be moved easily with the fingers, necessitating this operation. It has been noted that many operators make curved feelers .040-inch thick for setting the tappet clearance. This type gauge is very handy for checking the clearance.

3. Every twenty hours the cotter pins should be removed and the rocker arm-pin nuts (Part No. 19,415) checked for tightness. This is very important as any looseness on the part of this nut permits the rocker arm pin, sleeve and thrust washers to turn and is apt to cause serious wear in these parts.

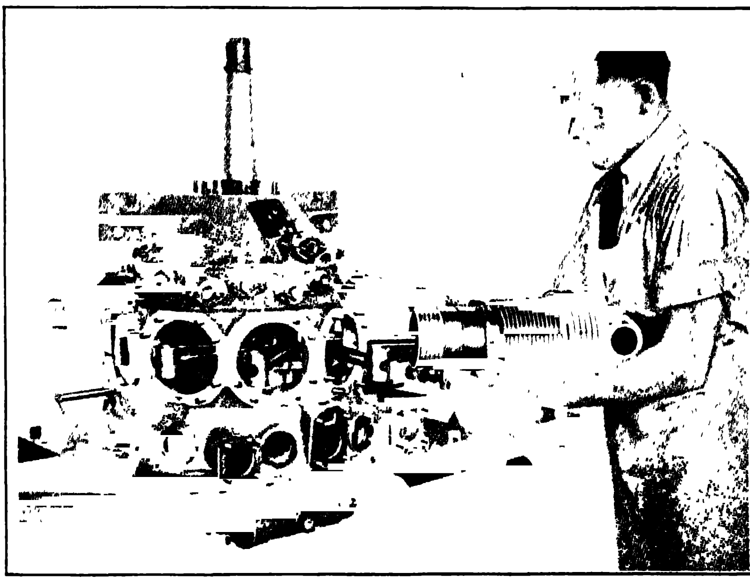


Fig. 590.—Showing How Wright Model J5 Engine Cylinders are Assembled on Engine.

4. It is most important to use the correct type of grease in the rocker arms of the "Whirlwind" as many types will become hard and carbonize at the temperature to which they are subjected. Grease containing soap and graphite is most objectionable in this respect and should never be used. Automobile transmission oil has been found satisfactory for rocker arms but care should be exercised not to over-grease these parts as the lubricant may get on to the hot valve stems and stick the valves by the carbon formation. When Uniflow lubricators are used for long endurance flights, vaseline is found satisfactory as it flows at the proper rate to give lubrication for a number of hours.

It has been noted that the clearance between the ends of the piston rings was omitted on the drawings. This is .008-inch to .011-inch. Replace when the gap reaches .050-inch.

8—Ignition System.—Replace the ignition system in the reverse order of disassembly.

9—Timing.—The engine is then ready for timing. The rear face of the propeller hub is marked with the proper angles and can be used in this operation. When it is not desired to remove the hub from the propeller, or when a metal propeller is being used, timing disk WA-138 and hub WA-265 are necessary. Put on whichever hub is to be used. Insert top center indicator WA-43 into the front sparkplug bushing of the No. 1 or top cylinder (rear bushing on J4A and some J4B engines). Set the tappet clearance on the No 1 cylinder valves at the proper value for timing. For all models this is .060-inch. Use tool WA-197. With a piece of sheet metal and a pair of shears make a pointer and attach loosely to the engine on the two top nose plate studs.

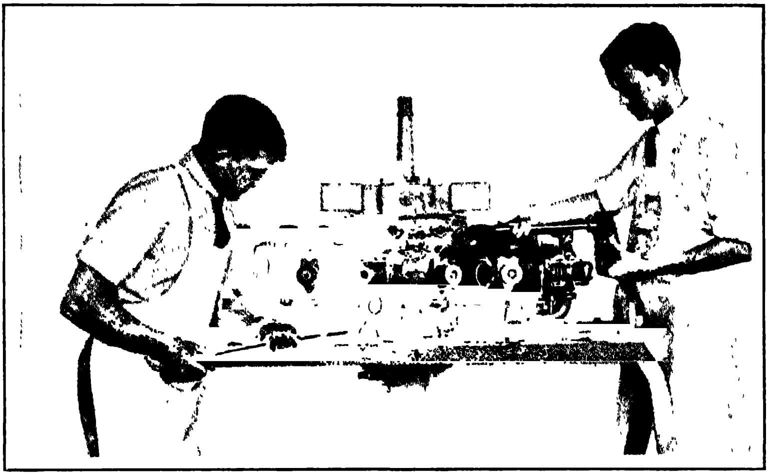


Fig. 591.—Assembling Intake Pipes and Valve Gear Housings on Wright Model J5 Engine Using Tool WA-225.

Remove the cotter pin and loosen the hex nut on the end of the cam and magneto drive shaft. This is located in the nose of the engine directly above the crankshaft. Remove the breather (J4A and J4B) or the plug (J5) located on top of the crankcase front section directly between the magnetos. Set the No. 1 piston on top dead center as shown on the indicator. Adjust the sheet metal pointer to the No. 1 cylinder T.C. mark on the hub. If the timing disc is being used, secure the pointer tightly to the engine and make a mark opposite on the disc. Rotate the shaft until the intake valve on the No. 1 or top cylinder begins to open. This point is best determined by rocking the tappet roller with the thumb and forefinger and noting the point at which it comes into contact with the valve end.

Remove the timing disc or hub, being careful not to disturb the setting of the cam. Insert a screwdriver through the breather hole and separate the serrated discs, or timing dogs. On the Model J5 the serrated surfaces

are between the hub faces of the magneto and cam drive gears, while on the J4 series engines they are located in front of the two gears. Replace the hub and turn crankshaft in the direction of rotation until the pointer indicates eight degrees before the top center mark previously mentioned. Engage the dogs and secure by turning up on the cam drive shaft nut. Check the setting of both intake and exhaust valves. As cams are subject to slight variation it is probable that when the intake opens at eight degrees before top center the exhaust will close at from eight degrees to ten degrees after top center. Whatever this difference is it should be split and

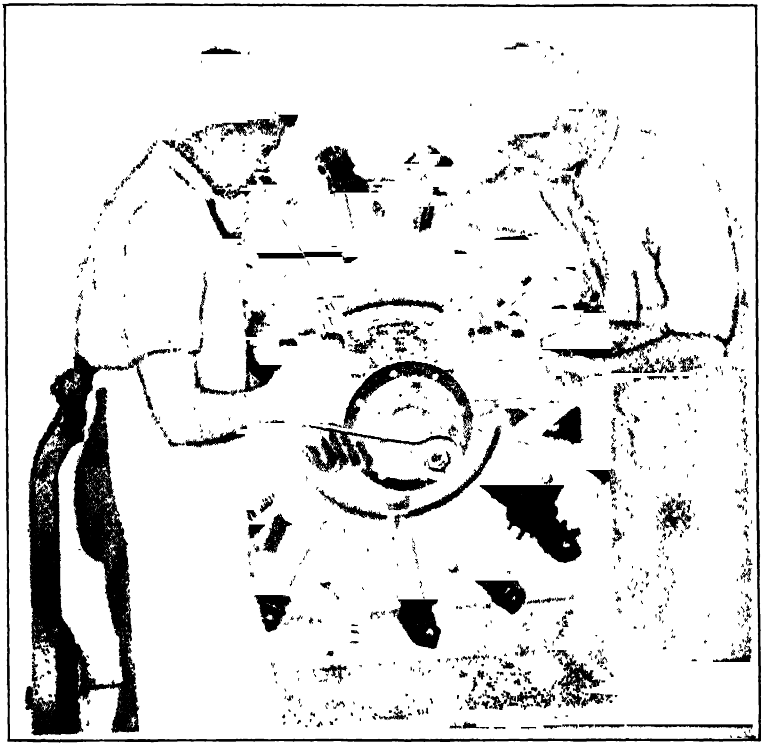


Fig. 592.—Method of Checking Magneto Timing of Wright J5 Engine Using Tools WA-110 and WA-138.

added equally to both sides so the valves operate at equal angles on either side of top center. When the timing is correct tighten and cotter the cam drive shaft nut. Replace the breather cap (J4A and J4B) or plug (J5). Remove the top center indicator.

To adjust the magneto timing first set the No. 1 cylinder on the compression stroke at 30 degrees before top center as indicated on the hub or timing disc. If the valve timing has just been adjusted this is done by turning the crankshaft through approximately one complete revolution. Then set the magnetos on the No. 1 cylinder with the breaker points just separat-

ing. To do this proceed as follows:—Push the coupling towards the magneto until it disengages from the engine drive gear and rotate until the firing point of the No. 1 cylinder is reached. This occurs when the marks on the distributor drive gear coincide with those on the casing. The right side of the magneto has double marks, while the left side has single. The firing point can also be determined by watching through the small observation window noted on the photograph until the numeral "1" appears. The exact location of the point is obtained by putting a slight tension on a piece of thin paper held between

Fig. 593.—Method of Checking Valve Timing of Wright Model J5 Engine Using Tools WA-110 and WA-138.

the breaker points. When the points separate and the paper is released, hold this setting securely, disengage the coupling completely, and rotate until the two pairs of gears engage. Repeat with the other magneto. As soon as both are timed, a check should be made to see that the two are synchronized. Insert pieces of paper between the breaker points and rotate the crankshaft until both are released. The difference between the two should not exceed one-half of one degree. This operation is illustrated at Fig.

12. Make sure that no paper is left between the breaker points. Cotter the couplings and replace the distributor blocks and breaker mechanism covers.

10—Rear Section.—The rear section should then be replaced. Coat the rear end of the crankshaft and the bronze bearing inside the rear section with oil and slide the rear section into place. Replace the retaining nuts and washers. The bottom stud is behind the oil strainer and on account of its position is liable to be forgotten. Oil the shaft on the accessories drive gear and tap it into place rotating the accessories gears until they are in mesh. Tap the starter dog into place in the end of the drive gear and lock both in the shaft with the long steel screw. Replace the starter.

11—Tappet Clearance.—On the J4A and J4B models the tappet clearance is set at .010-inch for both intake and exhaust. The adjustment is made on the upper end of the push rods where the ball end shank screws into the rod proper. Keep the rod from rotating by means of a wrench on the hex provided for that purpose, loosen the lock nut, and then screw the ball end in or out until the .010-inch feeler (WA-81) becomes a snug fit between the roller and the valve plug (Fig. 593). Bring the lock nut up tight against the rod and then check the clearance to make sure the ball end has not rotated while being locked. The adjustment on the Model J5 is quite different, the clearance for both tappets being .040. Loosen the clamping screw on the push-rod end of the rocker arm and with a large screwdriver turn down on the adjusting screw until the rocker roller touches the valve plug. Then back off on the adjusting screw until the arrow on top has passed eight divisions of the scale on the rocker arm (each division is equivalent to .005-inch clearance on the valve stem). Lock in place by tightening the clamping screw.

In setting the tappet clearance it is essential that the piston of the cylinder in question be at top center on the firing stroke. Unless this is done, it is quite possible for one of the tappets to be riding unnoticed on the rising part of a cam, causing an error in the tappet setting. To avoid the possibility of making this error proceed as follows: Turn the crankshaft until the valves of the No. 1 cylinder indicate that the piston is on top center at the beginning of the suction stroke. At this point both the valves will be open and the keyway in the shaft will be facing the No. 1 cylinder. If the propeller is mounted on the shaft one of the blades will be in the line of the keyway. Then turn the shaft through one complete revolution and set the clearances on the No. 1 cylinder in the manner prescribed. Having done this, turn the crankshaft in the direction of rotation until the keyway or propeller blade is facing the No. 3 cylinder and set the clearances. Repeat on the rest of the cylinders, taking them in the firing order (1, 3, 5, 7, 9, 2, 4, 6, 8).

12—Miscellaneous.—Replace the carburetor. Replace the oil drain pipe. Replace the rocker box covers.

Installing J4B Cylinders on J4A Engines.—*Parts Cancelled* (Units per cylinder) 13,153 J4A cylinder machining assembly (1) 18,823 Intake pipe (1) 18,012 Ignition wire sleeve (2) 13,091 Ignition wire bracket assy. (1) 18,858 Ignition wire tube (1) 18,938 Ignition wire tube (1). *Parts Added* (Units per cylinder) 13,556 J4B cylinder machining assembly (1) 19,561 Intake pipe (1) 19,677 Ignition wire tube straight (1) 19,562 Ignition wire

tube (1) 14,941 Lock washer (4) To install a J4B cylinder on a J4A engine the following operations are necessary:—1. Remove J4A cylinder and intake pipe in the usual manner. If No. 1 cylinder is changed, great care should be exercised in keeping the master rod on the cylinder center line, as the piston rings on the other cylinders will catch above or below the cylinder sleeves if the master rod is cocked away from its normal position

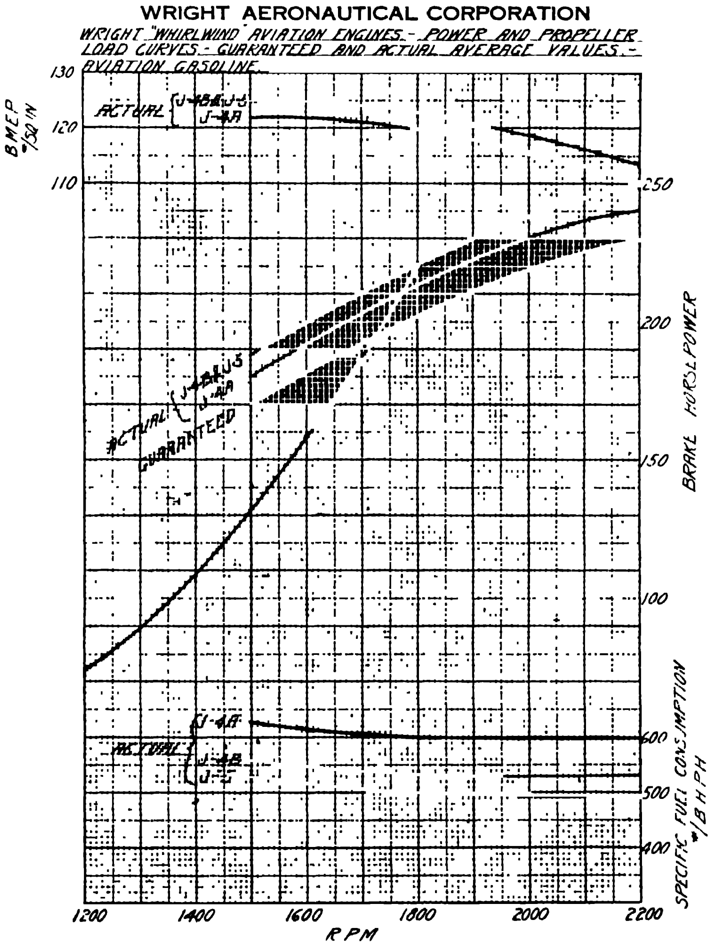


Fig. 594.—Power and Propeller Load Curves, Guaranteed and Average Actual Values of Wright "Whirlwind" Aviation Engines.

2. Cut Rajah terminal off top sparkplug ignition wire and pull the wire back through the ignition wire tube 18,858 to 18,938. 3. For cylinders Nos. 1, 2, 3, 4 and 5 thread this wire through the ignition wire manifold to the next lower opening. For cylinders Nos. 6, 7, 8 and 9 pull the wire

back through the next opening above its former location. This will bring the wire out just below the front sparkplug in the new cylinder. If all cylinders are being replaced it is possible to shift wires in the distributor blocks so that the wire going to the head plug is used for the previous cylinder, i.e., No. 6 is used for No. 5 and No. 1 for No. 9, etc. If this is done no alterations in wire location in the ignition wire manifold are necessary.

4. Fit J4A valves, springs, rockers, sparkplugs, etc., to the J4B cylinder and install it in a manner similar to the J4A cylinder. Omit ignition wire bracket assembly 13,091 in the J4B assembly and fit four lock washers under the intake pipe nuts. 5. Thread the ignition wire formerly for the head sparkplug through the straight ignition wire tube 19,677, cut it off to the proper length and solder on the Rajah terminal. 6. Unsolder the Rajah terminal for the rear sparkplug, pull the wire out through the ignition wire tube 18,858 or 18,938 and remove the ignition wire tube. 7. Fit the ignition wire tube 19,562 in the same location and secure it with the clip on the intake pipe. 8. Resolder the Rajah terminal to the rear ignition wire. 9. Insert push rods and adjust clearances. 10. Run in gradually, increasing the speed and load for three hours before flying.

Wright J5 Carburetor.—The Stromberg Model NA-T4 carburetor furnished on the J5 engine embodies the same basic principles throughout as all Stromberg models and it is advised that a thorough study be made of the special chapter explaining Stromberg Airplane Carburetors, before attempting to master the details of this particular carburetor. It contains complete information on design, construction, operation, adjustment and servicing, and assimilation of this information, together with detail reference to the sectional drawing will make easy a complete understanding of the carburetor. The specification in the carburetor has been evolved after a great deal of painstaking effort by all parties concerned in the production and operation of the engine and carburetor, and represents the combined results of much dynamometer, torque stand and flight work. The specification should never be changed unless absolutely necessary, and then only when sufficient data are at hand to determine exactly the nature and extent of the change. The specification is given on an aluminum tag riveted to the carburetor, and as originally worked out for this engine calls for a No. 52 main metering jet and 1$\frac{7}{16}$-inch venturi.

The NA-T4 Carburetor.—There are in service three sub models of this carburetor, the NA-T4, the NA-T4A, and the NA-T4B. They are all essentially the same, the differences being minor ones. The NA-T4B has a revised system of float chamber venting. The NA-T4A is designed for use on the pressure side of a supercharger. It has packing glands on the idle adjustments and on the operating end of the throttle shaft. The other end of the shaft is completely blanked off from the outside. All models embody a packed gland on the mixture control valve stem. The instructions following apply to all models of the carburetor with equal force and no distinction is made among them. The NA-T4 and NA-T4B Models are illustrated in Fig. 595. The Model NA-T4 carburetor has three barrels of 1$\frac{5}{16}$-inches actual internal diameter. The float chamber is in two parts,

one front and one rear of the three barrels, which are arranged in a row. The two divisions of the float chamber are connected together as are the two floats so that the net effect of the construction is that of a single float chamber with its center in the center of the carburetor. The fuel level in the discharge nozzles is thus held constant for any change of position of the airplane either on the ground or during normal flight. Each of the three barrels acts as a separate carburetor though they all draw from a common float chamber. Each has complete separate main discharge and idling systems. The throttle valves are all on a common shaft and are, therefore, operated by a single lever. The three barrels are balanced together around the venturis and this, in conjunction with the common float chamber, allows of the use of a single mixture control. The strainer is located at the left rear corner of the carburetor immediately in front of the fuel inlet boss. The main metering jets are in the bottom of the accelerating well screws and are reached by removing the plugs underneath the main discharge bosses. The carburetor is particularly designed to give positive and regular operation in catapulting, on a rough take-off or when flying in very rough air. Both the throttle and mixture control lever operate in a fore and aft direction.

For starting the engine the general practice given in the chapter on Stromberg Carburetors is recommended It can readily be seen that with the low speeds used in cranking, it is much easier to start the idle system to functioning than the main well. In starting, therefore, the throttle should be kept closed, or nearly closed, until the engine fires.

These carburetors are of the plain tube type and there are no moving parts to wear. Once set for the engine, they should function properly at all times, unless there is some actual part breakage, stoppage of fuel or similar failure. The throttle shafts are of duralumin and are held in brass bearings. The float pivot pins are of monel and work in brass bushings. There should be no evident wear after several hundred hours of service. The range of idle adjustment on these carburetors is in excess of that needed to care for any variation in engine requirements. It is effective only from extreme idle to approximately 600 or 700 r.p.m. of the engine. That is to say, it is intentionally so designed that any specific idle adjustment required for a particular engine condition will not affect the main running range. The adjustment is made by swinging the small lever on the quadrant. Care should be taken in making this adjustment. Primarily it is, of course, necessary to furnish the engine with the proper mixture to insure all cylinders firing at all times smoothly and positively. The adjustment should be made when the engine is warm but the operation cold should be taken into account by setting the mixture as rich as possible and still fulfill all engine requirements for good operation in a warm condition.

As noted above, a separate idling system and, therefore, a separate adjustment is provided for each barrel. The barrels or manifolds are at no point inter-connected above the throttle and each barrel, therefore, feeds three cylinders separately and distinctly. The manifold arrangement is such that the left barrel feeds cylinders 2, 5, 8, the center barrel, cylinders 1, 4, 7 and the right barrel the remaining three. This arrangement spaces evenly

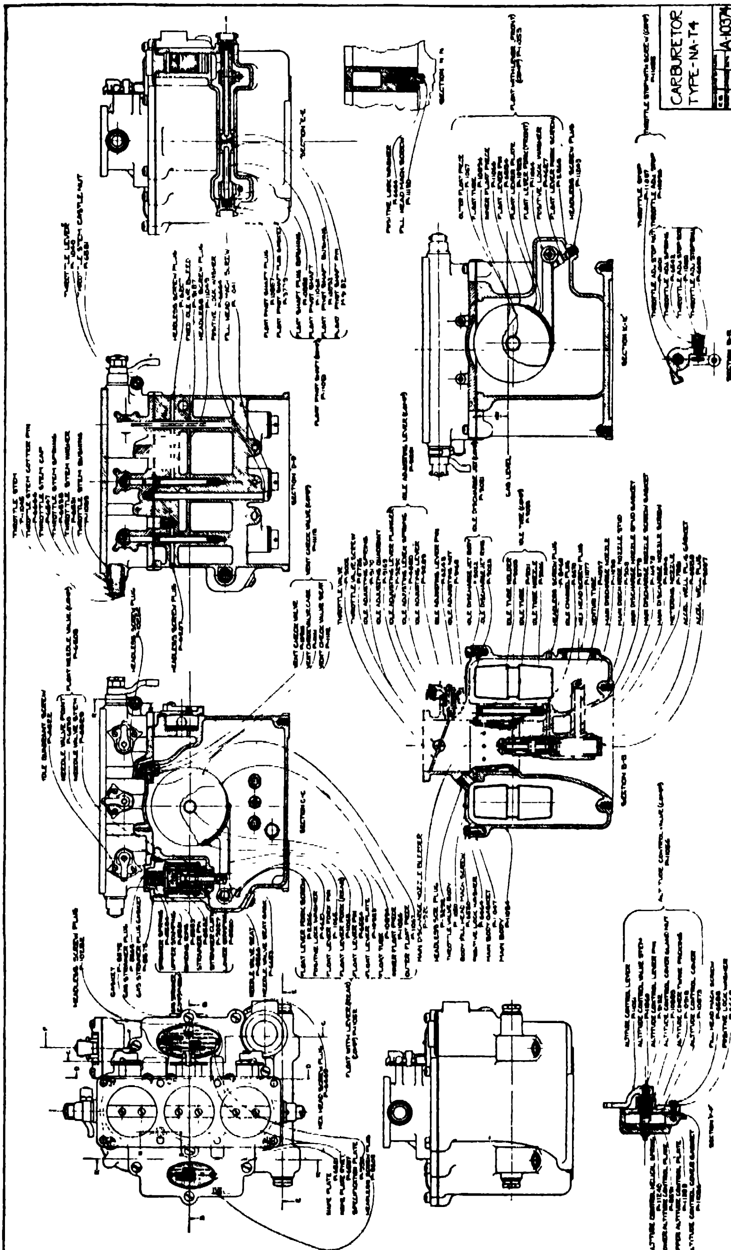


Fig. 595.—Drawings Showing Construction of the Stromberg Type NA-T4 Carburetor Used on Model J5 Engines.

the pulsations or air flow periods in each barrel. Utilization of this knowledge is essential in obtaining a correct idle adjustment. It is not necessary that the exact cylinder numbering and carburetor barrel relation be known It can easily be determined by observing the effect of the different adjustments when the engine is idling. To do this, set all of the idle adjustments as lean as possible, still maintaining an evenly firing engine. Then throw one adjustment into the full rich or nearly full rich position. Note carefully the cylinders which show a heavy black smoke in the exhaust with indications of uneven firing. These cylinders will be separated by threes; for example, they will be 1, 4 and 7. Adjusting this idle back to the lean position, give the engine time to "clear out" and repeat with another adjustment. It is not necessary to check the third adjustment as this will, of course, affect the remaining three cylinders All of the idle adjustments operate in the same direction, that is, they all turn to the right or clockwise to richen and to the left or anti-clockwise to lean the mixture.

The carburetors should at every opportunity be checked carefully to see that all parts, screws and connections are tight and that all controls are functioning properly. The fuel strainer in the carburetor should be cleaned regularly. It is possible for minute particles of dirt to lodge between the float needle and seat and cause the carburetor to flood. Sometimes this flooding can be stopped by tapping the carburetor with some soft instrument or tool (such as a rawhide mallet or wooden screwdriver handle). Or the carburetor can be flushed out by removing one of the bottom plugs in the float chamber or one of the plugs beneath the main discharge nozzles. If the carburetor shows persistent flooding, it should be removed, the halves separated and the cause located.

Carburetor Overhaul.—As noted under "Bench Inspection," in Chapter X the carburetor at any time it is deemed necessary, may be partially disassembled and given a thorough inspection to determine its condition. It is recommended that this be done in all cases of doubt. The operation of the engine depends to such a large extent upon the carburetor that its condition should be kept at all times as nearly perfect as is possible. For an overhaul, the carburetor should be almost completely disassembled so that the condition of every part can be determined. An aircraft carburetor which is properly overhauled should be in exactly the same condition as a new one. This requires a thorough knowledge of the carburetor and painstaking attention to every detail of disassembly, examination and reassembly. The procedure given should be followed in all particulars. The illustrations of the carburetors should be examined carefully, with particular reference to the actual mechanical construction so that the disassembly and re-assembly can be properly made. The carburetors have been designed in so far as possible to require no special tools. However, as is necessary for all good work, the best of tools should be used and only those which are exactly fitted to the work. Particular care should be taken to see that gasket surfaces are not injured.

Especial care is also required for the proper assembly and disassembly of the float mechanism. This is made of sturdy construction to stand hard service, but it is necessary for proper operation that it be assembled with the pivots accurately lined up, and with the needle in its proper location at

all positions of operation so that there is no tendency to bind. Be certain that the float does not rub on the carburetor walls. To disassemble the Model NA-T4 carburetor, it is necessary first to remove the twelve fillister head screws which fasten the two halves of the carburetor together. Ten of these screws are put in from the top and are plainly visible. The other two are reached from the bottom of the carburetor by inverting it. Of these two, one is quite long and reaches nearly to the bottom flange surface. The other is short and lies between and behind the venturis. It cannot be mistaken if there is knowledge of its presence and general location. Because it is partially hidden, it is often forgotten and in such case the halves of the carburetor obviously cannot be separated Sometimes the halves stick together after long service but will loosen easily with a few light blows from a rawhide mallet on the lower half, holding the upper half securely in one hand.

The venturis are held in place by shoulders on the venturis themselves, which fit into grooves of the parting surface When the halves are separated, the venturis can be removed. Unscrew the plugs in the bottom of the main discharge nozzle bosses. Unscrewing the accelerating well screw will then allow the removal of the main discharge nozzle proper and the accelerating well stud. After these are out, the accelerating well studs should be unscrewed from the main discharge nozzles. The location of the gaskets removed should be carefully noted so that they can be put back correctly in place when the re-assembly is made. Remove the strainer from the strainer chamber.

The float mechanism is of an uncommon construction, the floats being placed in the float chamber separately and then clamped rigidly to a common pivot shaft. To make this disassembly, the float needle valve and seat should first be taken out. It is not absolutely necessary to remove the needle valve and seat in order to get the float mechanism disassembled and out of the carburetor but it is more easily done in this manner and it is necessary that the needle valve seat be removed before the re-assembly can be made. Care must be taken with the valve seat (it will be found to be very tightly in place) both to see that the screwdriver slot is not injured and to keep intact the gaskets under the seat. These gaskets determine the float level and if put back in place exactly as removed, the float level will be the same.

Next, remove the two plugs at the bottom of the two bosses on the left side of the carburetor The small screws which clamp the float arms to the pivot can be reached by a small screwdriver inserted through these holes. After loosening these, the two pivot bearings in the end should be unscrewed. These should be marked so that each can be returned to the same side from which removed. It will be noted that the pivot shaft is hollow and has in each end a length of 10-32 female thread. Any screw or bolt having this thread can be used to screw into one end of this for handling. The shaft should be pulled toward the end in which the screw is being used until the float arm of the float in the other end is clear of the shaft. This float should then be removed and the shaft moved in the other direction until the other float is clear and can also be removed. If the operation of sliding the pivot shaft in the float arms is done carefully, it is easily per-

formed, otherwise much injury and delay can be caused. There is ample clearance between the hexagon on the shaft and the hexagonal hole in the float lever if the two are properly lined up with each other. If they are not lined up, the lever binds on the shaft and prevents it from moving in either direction. The best method is to hold the float with the fingers of one hand while working the pivot shaft with the other. The "feel" of the float gives an indication of how easily the pivot shaft is sliding in the arm.

In replacing, the reverse procedure is, of course, gone through with. Particular attention should be paid the pivot shaft plugs. These act not only as bearings for the pivot shaft, but serve also to limit the end play of the float and shaft assembly. This end play should be the minimum consistent with the free operation of the float. Before placing the needle valve and seat back in the carburetor, they should be checked for leakage and examined carefully for evidence of wear or injury. Remove the idle air bleeders and the idle tubes by unscrewing out of the lower half. See that all drilled passages are open. The mixture control valve is opened to inspection when the cover is removed by unscrewing the small fillister head screws. If the mixture control valve is removed, mark it carefully as each valve is individually fitted and they are not interchangeable.

If the throttle valves fit accurately and the throttle shaft works freely in its bearings, they should not be loosened or disturbed in any manner. The most difficult task of assembly of the entire carburetor is in getting these valves properly fitted and synchronized all on the same shaft. In case of removal the throttles should be marked for refitting. They are machined accurately at the exact angle they lie in the carburetor barrel (twenty degrees with the horizontal). The barrels are carefully finished with a reamer which is held to within five ten-thousandths of an inch in size. In the reaming, however, the barrels attain different degrees of heat and there may be slight variations in size. For this reason the throttles are fitted individually on the original assembly. Therefore, when removing them, mark carefully so that each throttle is returned to the proper barrel with the proper face up and all points on the circumference in exactly the same location as before removal. The hexagon head plug which holds the idle adjustment assembly in place should be unscrewed and the assembly removed.

Carburetor Re-assembly.—The assembly of the carburetor is, of course, just the reverse of the process given above with the following addition: after the assembly of the lower half, the float level should be checked and if not right, corrected. In making the re-assembly, too much care cannot be exercised in seeing that all necessary gaskets are in place. There are many gaskets in the carburetor and the omission or improper placing of any one of these may cause complete failure of the carburetor action. In assembling the upper and lower halves of the carburetor together, it should be made certain that they fit well. As covered above the venturi tubes are held in place by shoulders machined on the tubes themselves fitting into grooves in the upper half. The thickness of the shoulder and the depth of the groove are nearly the same so that the venturi will be held tightly in place and will not move under vibration. Check carefully to see that the venturi shoulder will not hold the two halves apart, for should it do so, the

resulting action will be the same as that from an imperfect main body gasket. The assembly of the two halves is best made by having the venturis in place in the upper half as the assembly is started, making certain that the venturis are in the proper position to let the slots in the bottom fit over the main air bleeder arms.

Three points are of vital importance in the re-assembly of the carburetor. They are:

The Main Body Gasket.—This should be in perfect condition. If the gasket is torn at any point around the float chamber or any of the mixture control drillings, it will not only allow fuel to seep out of the carburetor, but will seriously interfere with the mixture control action. If torn or imperfect around the idle tubes, it will cause poor idling operation and even cause the engine to cease firing entirely. If the gasket allows any connection between idle tubes and the float chamber, the engine will not run between 600 and 1,200 r.p m.

The Idle Discharge Jets.—These should fit perfectly in place without forcing and should rotate freely. All three adjustment assemblies are different and each must, of course, be returned to its proper barrel.

The Float Level.—The effect of the float level is so great on some of the operating characteristics of the carburetor that its proper location is of the utmost importance A too high level gives flooding and consequent fire hazard, wastage of fuel, etc. If too low, there may be poor operation of the engine from 600 to 1,200 r.p.m. with possible "backfiring" and in addition poor or no acceleration when the throttle is suddenly opened. The level should be exactly correct with the fuel and operating head used in actual service and there should be no "creeping" of the level.

QUESTIONS FOR REVIEW

1. What is the difference between the "Whirlwind" J4 and J5 engines?
2. What outstanding accomplishment gave the "Whirlwind" engine world-wide recognition?
3. What is the difference between J4 and J5 "Whirlwind" cylinders?
4. What induction system is used on J5 "Whirlwind" engines?
5. Why can "Whirlwind" crankshaft be one piece?
6. What type fuel pump is used on Wright engines?
7. What system of lubrication is used with Wright engines?
8. Outline principal Wright "Whirlwind" troubles and remedies
9. Describe inspection routine for "Whirlwind" engines
10. When is a complete overhaul needed with Wright "Whirlwind" engines?

CHAPTER XXXIV

WRIGHT CYCLONE ENGINE

General Description—Cylinders—Crankshaft—Crankcase—Supercharger—Valve Operating Mechanism—Valves—Valve Spring Assembly—Pistons—Lubricating System—Magnetos—Ignition Wiring—Carburetor Air Heater—Hand Starter—Specifications for Wright Cyclone Engine, Model R1750—Starting and Normal Operation—Starting—Ground Test—Flight Operation—Landing—Fuel Specifications—Oil Specifications—Engine Troubles—Low Power and Uneven Running—Excessive Oil Temperature—Cold Weather Precaution—Inspection Routine—After Twenty Hours—Overhaul—Disassembly—Cylinders—Front Section—Intermediate Section—Articulated Rods—Crankshaft and Master Rod—Rear Section—Oil Seal—Crankcase—Inspection and Repair of All Parts—Cylinders—Pistons and Rings—Valves—Valve Guides—Rocker Arms and Cam Followers—Cam—Crankcase Parts—Supercharger Impeller—Crankshaft Inspection—Supercharger Oil Seal—Re-assembly of All Parts—Checking the Timing Supercharger Section—Supercharger Drive—Magneto Timing—Installation and Test after Overhaul—Instructions on Stromberg NA-Y7A Carburetor—The Wright J6 Engines.

The Wright Cyclone aviation engine, Model R1750, shown in photographic reproductions at Figs. 596 and 597, is of the nine-cylinder, air-cooled, static, radial type operating on the conventional four-stroke cycle. The bore is six inches and the stroke is 6⅞ inches giving a total displacement of 1,750 cubic inches. This model is rated at 525 brake horsepower at 1,900 r.p.m. but will develop 535 brake horsepower at that speed and under standard conditions. The guaranteed fuel and oil consumptions at rated power and speed are .55 and .035 pounds per horsepower-hour respectively.

Cylinders.—The cylinder is built up by screwing and shrinking a forged-steel barrel into a cast-aluminum head as clearly shown in sectional view at Fig. 598 The head and fins are cast in aluminum alloy, the bottom fin being quite heavy to give additional strength at the threaded end. The valve ports both face the rear of the engine. The exhaust port is furnished with several cooling fins and the intake is left bare. The valves are inclined to the center line of the cylinder at angles of 37.5 degrees, permitting a hemispherical combustion-chamber. Valve guides of tungsten steel are shrunk into the cylinder head. The valve seats are of bronze and are also shrunk into the head. The cylinder barrel is machined from a steel forging, and is supplied with fins and the hold-down flange. The top end is furnished with threads for a distance of 31/32 inch where it screws into the head.

Crankshaft.—The crankshaft is of the two-piece, single-throw, counter-balanced type machined from nickel-steel forgings as shown at Fig. 600. The front section of the shaft includes the crankpin, the front crankcheek and counterweight, and the shaft proper. The crankpin is bored out for lightness throughout its length except for the rear end where a heavy circular rib is provided to prevent distortion when the rear section is clamped on. The crankcheek is of rectangular section between the crankpin and

the shaft proper and, below the crankshaft centerline, is provided with a slotted extension to carry the bronze counterweight. The power is transmitted to the propeller through the hollow front section of the shaft which has splines machined in the forward end. A steel sleeve pressed onto the shaft next to the crank throw provides a journal for the crankshaft front bearing and provision is made for a ball thrust bearing and retaining nut near the front of the shaft. The rear section of the crankshaft is composed of the rear crankcheek, counterweight and the crankshaft rear-bearing ex-

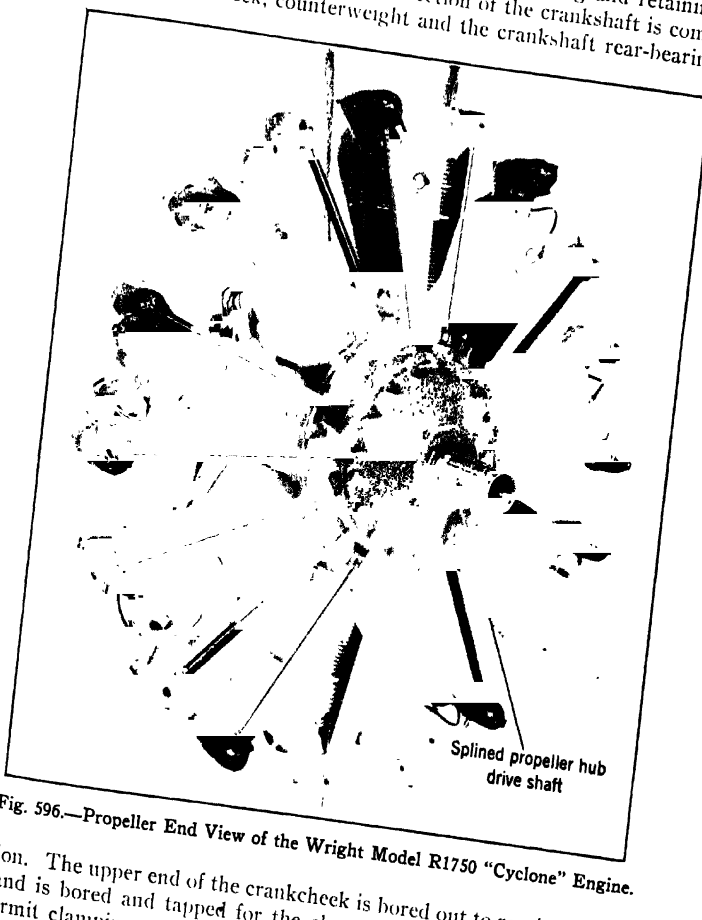


Fig. 596.—Propeller End View of the Wright Model R1750 "Cyclone" Engine.

tension. The upper end of the crankcheek is bored out to receive the crankpin and is bored and tapped for the clamping screw. A slot is provided to permit clamping action when the screw is tightened up. A hardened-steel washer under the clamping-screw head prevents scuffing the crankcheek when tightening up the screw.

Oil is fed under pressure into the front main bearing and is conducted from the center of that bearing to the crankpin bearing through a steel tube pressed into the shaft as shown in sectional view at Fig. 598 which also

shows the crankshaft construction clearly.

Crankcase.—The crankcase is built up of five sections cast in aluminum alloy. The front cover contains the main thrust bearing held in a steel housing. The intermediate section furnishes support for the cam followers and the cam-drive gears. In this section, also, the cam drum rides on a sleeve on the crankshaft. The main section of the crankcase is supplied with the cylinder pads and, in the rear wall, with the housing for the rear crankshaft bearing. The supercharger is located in the main section be-

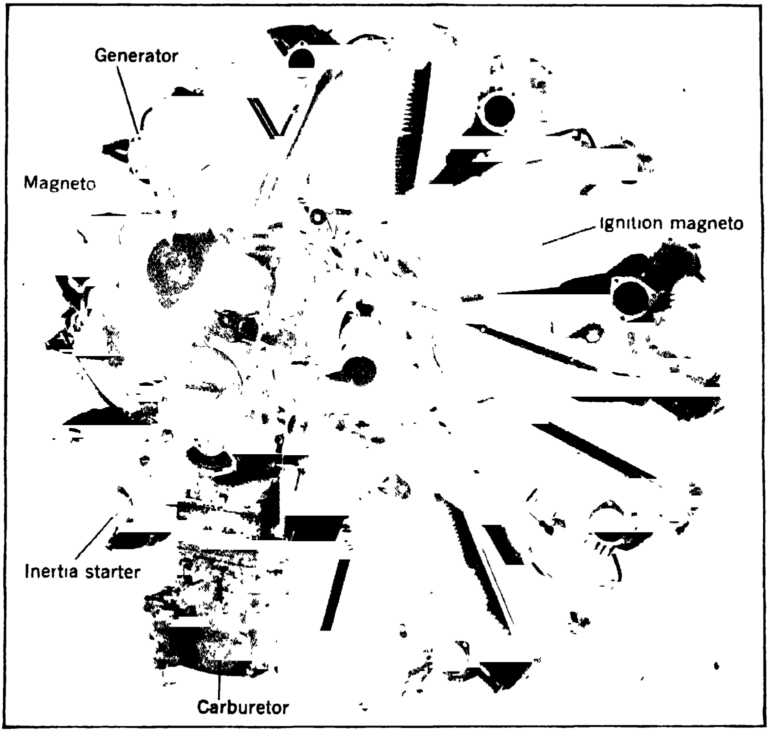


Fig. 597.—Anti-Propeller End View of the Wright Model R-1750 "Cyclone" Engine Showing Accessory Grouping.

tween the rear wall and the supercharger section, this being the next section to the rear. The supercharger is described in detail in the next paragraph. The rear section houses all the accessory drives and supports the carburetor as shown at Figs. 598 and 601.

Supercharger.—The supercharger, which is of the centrifugal type, consists of an impeller, impeller drive, diffuser and distribution chamber. The impeller is 7.5 inches in diameter and is machined from a duralumin forging. It is mounted on a hollow steel shaft turning on ball bearings and operates with the inlet side facing the rear of the engine as clearly depicted in sec-

tional view at Fig. 598 The diffuser is a narrow annular passage surrounding the impeller through which the mixture is discharged into the distribution chamber. The front face of the diffuser is formed by a machined disc which is secured to the rear wall of the crankcase main section and at the center of this disc is an oil seal which prevents the supercharger from sucking oil out of the crankcase. The rear wall of the diffuser is the front face of the supercharger section casting. The distribution chamber

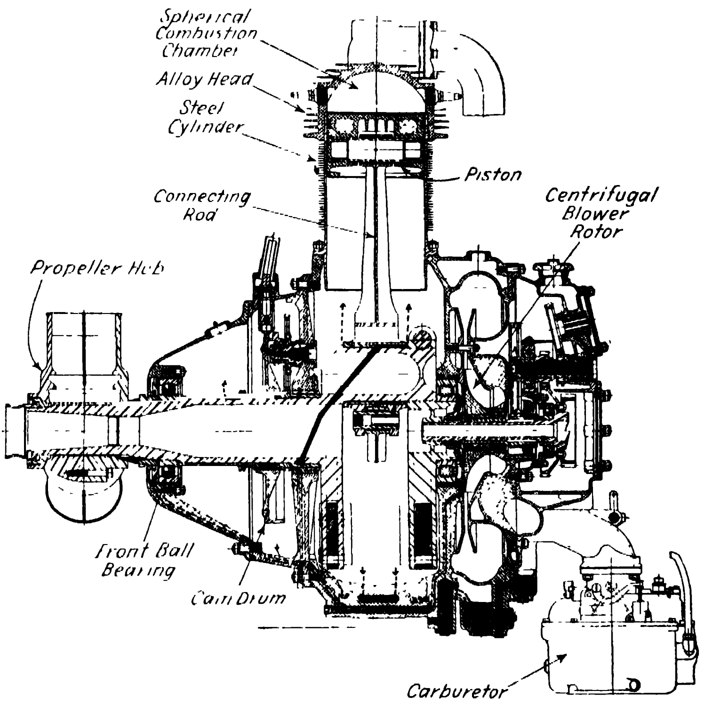


Fig. 598.—Part Sectional View of Wright "Cyclone" Engine Showing Lubrication System and Construction of Internal Mechanism. Note Centrifugal Supercharger Installation.

is an annular ring inside the rear of the main case, into which the diffuser discharges. The intake pipes are attached to this chamber by ports tangential to the circumference. The supercharger and all of the accessories are driven by an extension on the crankshaft which carries two gears on its rear end for that purpose. Directly above this extension is the supercharger and generator driveshaft. The front end of this shaft is carried by a ball bearing and the rear end runs in a bronze bearing in the crankcase rear section.

The silhouette drawing at Fig. 602 shows the general arrangement of the supercharger. The front gear on the crankshaft extension meshes with

a gear on the driveshaft, while the front gear on the driveshaft meshes with a gear on the impeller shaft. The impeller shaft is hollow and is concentric with the crankshaft extension. The gear ratio is such that the impeller rotates at eight times the engine speed.

Valve Operating Mechanism.—The cam, which is located in the intermediate section, consists of a hardened-steel ring with four pairs of lobes on the outside and an internal gear cut on the inside. The cam is riveted to an aluminum hub provided with a bronze-backed, babbitted bearing which rides on a steel sleeve on the crankshaft. This is shown in sectional view

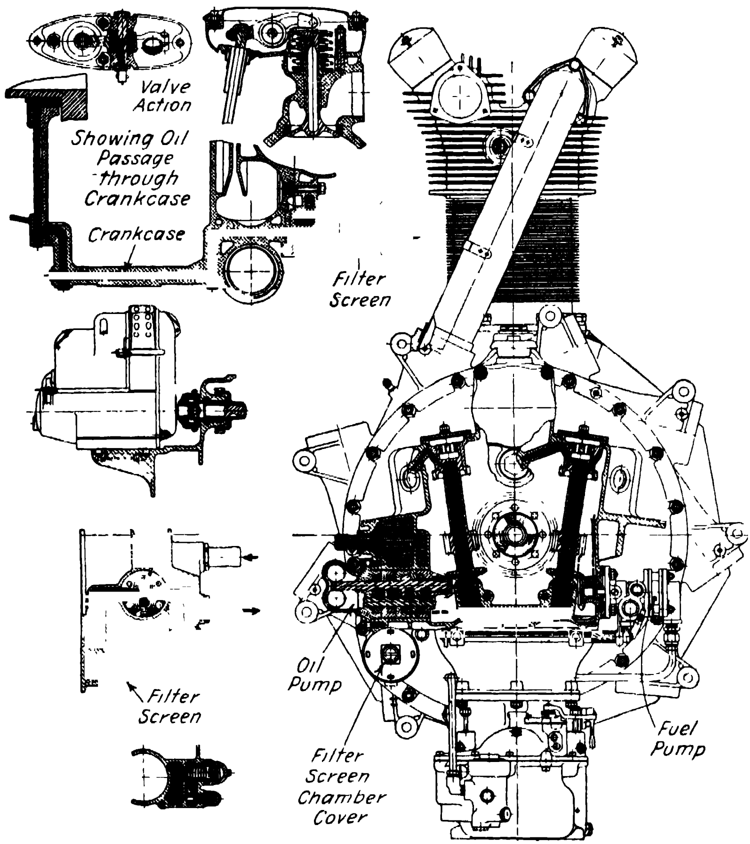


Fig. 599.—Part Sectional Views of Wright "Cyclone" Engine Parts Showing Lubrication System.

Fig. 598. The camdrive consists of a gear on the crankshaft and two gears rotating on a pin anchored to the rear wall of the intermediate section. One of these two gears meshes with the internal gear of the cam, driving it at ⅛ crankshaft speed and in the opposite direction. The other gear meshes with the drive gear on the crankshaft.

The cam follower tappet guides are machined from steel forgings and are arranged around the outside wall of the intermediate section. The tappets are of hardened steel and are a very close, sliding fit in the guides to prevent oil leakage. A hardened-steel cup is pushed into the upper end while the lower end is slotted to receive the cam-follower roller. The roller operates on a floating pin. The rocker arms which are shown at the top of Fig. 599 are of one-section machined from steel forgings. The valve end of the rocker arm is forked and carries a roller operating on a hub and pin riveted into the arm. The push-rod end of the rocker arm is provided with the tappet-clearance adjusting screw and adjusting screw locking screw.

Valves.—The valves are both of the tulip type, machined from tungsten-steel forgings. Twice during the machining process they are pickled in acid and inspected for flaws, thus insuring a uniform product. The exhaust-valve stem is hollow and is half filled with salt for cooling purposes, while the intake valve stem is smaller and is of solid cross section. The seats

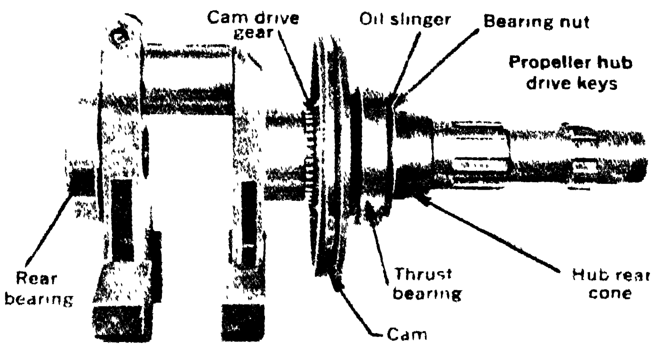


Fig. 600.—Crankshaft of Wright "Cyclone" Engine Assembled with Associated Parts.

of both are at an angle of 45 degrees. The valve seats are annular rings of cast-aluminum bronze shrunk into position in the cylinder head.

Valve-Spring Assembly.—The valve springs consist of three concentric coils of round music wire per valve. The lower retaining washer seats on the shoulder of the valve guides, and the upper washer is locked to the upper end of the valve by a tapered, split lockring. The inner spring is centered by the shoulders on the inside of the two retaining washers. The intermediate and outer springs are located by a ridge running around the contact face of each washer. This ridge is of such a diameter and thickness that it fits between the two springs.

Connecting Rods.—The connecting-rod assembly consists of a master rod and eight articulated rods machined from chrome-nickel-steel forgings. All rods are of one-section and finished all over as shown at Fig. 603 A. The master rod is of one-piece construction and operates in the No. 7 cylin-

der. It is provided with a steel-backed, babbitt-lined bearing at the big end and a bronze bushing at the wristpin end. The articulated rod knuckle pin and wristpin bushings are also of bronze.

The knuckle pins are of case-hardened steel and are finish ground all over. The front end is supplied with a flange which butts up against the face of the master rod in assembly. Each flange has a flat on one side which is used in conjunction with a flat, steel plate to hold the pins in place and prevent them from rotating. The plate is held in place by two screws which are lockwired together.

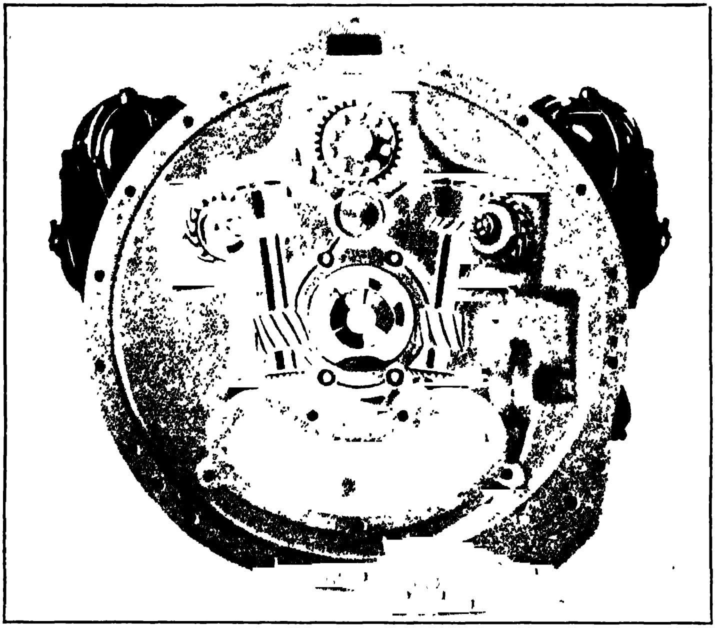


Fig. 601.—Rear Section Showing Generator, Magneto, Fuel Pump and Oil Pump Drives of Wright "Cyclone" Engine.

Pistons.—The pistons are of the full-trunk type cast is aluminum alloy as shown at Fig. 603 B. The under side of the head is heavily ribbed to increase the strength and improve the cooling. There are three piston-ring grooves, each holding a pair of narrow rings. Two of these grooves are above the wristpin, the top groove having two compression rings and the second two bevelled, oil-scraper rings. The third groove, which is at the bottom of the skirt, also holds a pair of oil-scraper rings. The upper oil scraper ring groove is provided with twelve ⅛-inch holes which return part of the oil scraped off the cylinder wall to the inside of the piston. The wristpins are of generous size machined from alloy steel and oil hardened. Aluminum alloy plugs in the ends prevent scoring of the cylinder walls.

Lubrication System.—The lubrication system is of the full-pressure type except for the cylinder walls, wristpins and accessory drive gears which are

lubricated by splash. Oil is carried in an external tank not furnished with the engine. The oil is drawn from the bottom of the tank and through a finger strainer by the pressure pump. The pressure pump forces the oil through the main strainer and then to the various parts of the engine as shown in sectional views at Figs. 598 and 599. One passage leads the oil

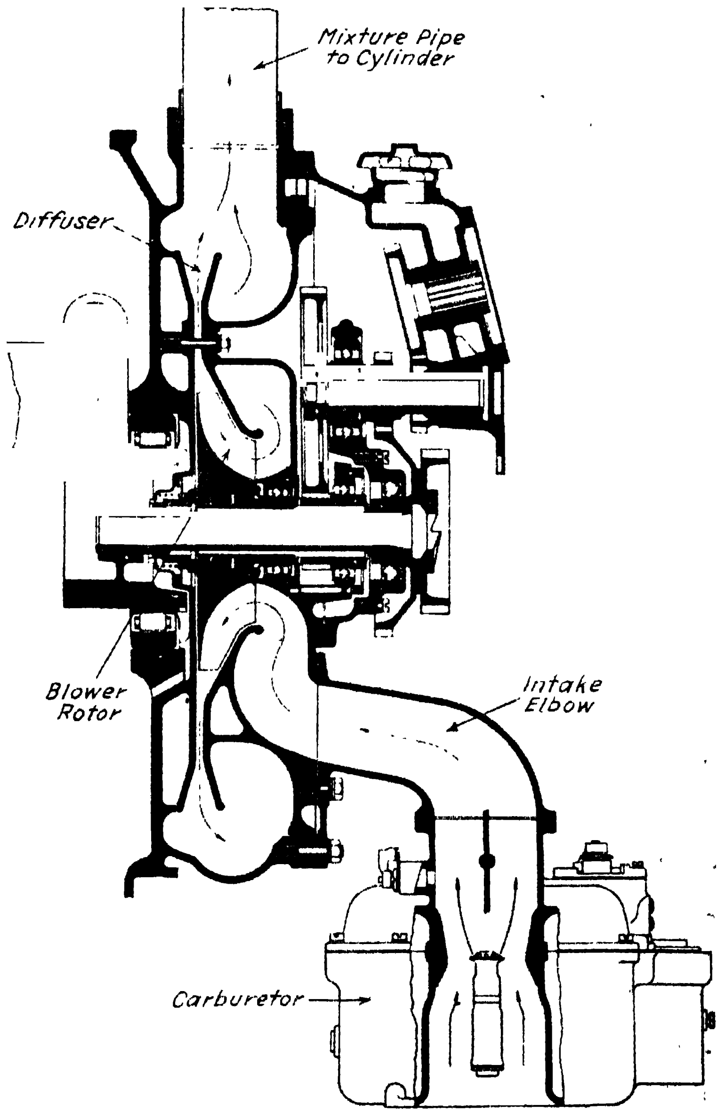


Fig. 602.—Drawing Showing GE Centrifugal Supercharger and Method of Rotor Drive Used on Wright "Cyclone" Engine.

to the rear of the crankcase intermediate section where it enters an annular groove cut in the casting behind the crankshaft front bearing. Four $\frac{5}{32}$-inch holes are drilled through the bearing opposite this groove and these holes index with eight $\frac{3}{32}$-inch holes in the bearing sleeve on the crankshaft. A groove in the inside of the bearing sleeve behind these holes is connected by a steel tube to the middle of the crankpin bearing. Four holes in the master rod bearing index with the end of the supply tube in the crankpin once every revolution. Grooves in the back of the bearing lead the oil from these four holes to a circular groove cut in the master rod inside the rear flange. Leads are drilled radially from this groove to the

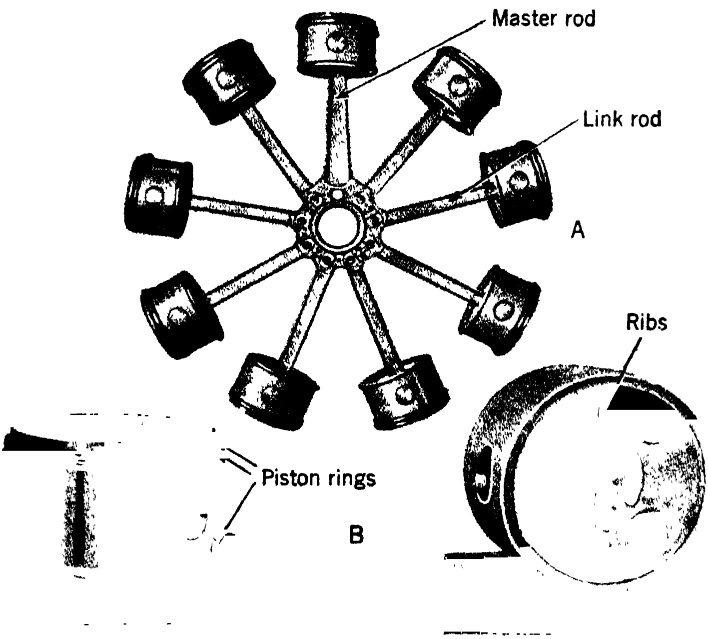


Fig. 603.—Wright "Cyclone" Engine Master and Link Rods and Piston Assembly Shown at A. The Construction of the Piston is Shown at B.

knuckle pin holes in the master rod flange. A hole in each knuckle pin indexes with the oil lead in the flange and conducts the oil into an annular space provided by an aluminum spool forced inside the hollow center of each knuckle pin. Another hole at the other end of this space delivers the oil to the connecting rod bearing.

Grooves in the back of the crankshaft front main bearing sleeve, in the cam drive gear and in the cambearing sleeve conduct oil to the cam bearing. Holes in the cam bearing and hub allow a part of the oil to escape and be thrown out on the cam drive gears. Drilled passages in the rear wall of the intermediate section conduct the oil to the camdrive pinion shaft and bearing. A passage in the crankcase rear section conducts the oil to the lower

ends of the two vertical shafts. These shafts are hollow and lead the oil to the upper ends, lubricating both the upper and lower bearing. Drilled passages leading from the upper ends of the shafts insure lubrication of the magneto, supercharger, generator drive bearings.

The oil-pump driveshaft is lubricated by seepage from the pump nearest to the driveshaft bearing. The fuel-pump driveshaft is lubricated by gravity feed from a small reservoir cast in the rear section just over the shaft bearing. This reservoir is open at the top and is constantly kept full of oil splashed off the drive gears and bearings. There are three scavenging pumps One of these is connected by passages to the front of the main section of the crankcase where it draws off the drainage from the front section and a part of that from the main section. The rear of the main section drains into a small sump which is drained by the second scavenging pump. The inlet to the third and innermost scavenging pump is an opening in the end plate of the oil pump assembly. This pump drains the rear section and discharges into the oil outlet connection common to all three scavenging pumps.

There are two oil pressure regulating valves, one of which is used to set the pressure at high speeds and the other to set the pressure at idling speeds The high speed, or main valve, is a spring loaded plunger valve which lifts from its seat when the desired pressure is reached and delivers the excess oil to the scavenging pumps Regulation is accomplished by turning in or out on the adjusting screw which raises or lowers the tension in the spring The low speed adjustment consists of a hole through the wall separating the pressure oil system from the scavenging system and a needle valve which seats in one end of this hole. This hole is of such area that at high speeds only a small percentage of the total oil circulating can be bypassed through it and its effect on the pressure is small. At low speeds a much larger percentage of the oil circulating is bypassed and the pressure can easily be regulated to secure the desired value of twenty pounds per square inch The needle valve extends outside the crankcase rear section casting where it is easily accessible. It is secured by a lock nut and covered by a screw cap

Fuel Pump.—The fuel pump is located on the right-hand side of the crankcase rear section The mounting pad is of the standard Army-Navy type and is adaptable to any one of several fuel pumps. The carburetor is the Stromberg Model NA-Y7A. Complete information on this accessory is given in the chapter on Stromberg carburetors and in the supplementary instructions to follow furnished by the Stromberg Motor Devices Company.

Magnetos.—Ignition is furnished by two Scintilla V-AG-9D magnetos mounted on the rear section of the crankcase. The right-hand magneto fires the front sparkplugs and the left-hand magneto fires the rear sparkplugs. They rotate at 1⅛ engine speed and furnish nine electrical impulses every two revolutions. Information on the construction and maintenance of the magnetos will be found in the special chapter furnished by the Scintilla Magneto Company in this book.

Ignition Wiring.—The wiring is rubber-insulated and covered with enamelled cotton braid to prevent wear and deterioration. A brass manifold running around the outside of the crankcase at the rear carries the

wires to the base of each cylinder from which point they run up the intake pipe to the sparkplugs. Clips on the intake pipe and on the cylinder head keep the wires from contact with the cylinder. Radio shielding can be furnished if desired.

Carburetor Air Heater.—The carburetor air heater consists of an aluminum casting which is attached with six fillister-head screws directly to the carburetor flange. A passage for exhaust gas runs through the casting horizontally at right angles to the engine crankshaft and is finned, both inside and out, to afford the maximum heating surface between the exhaust gas and intake air. This is shown immediately above the carburetor at Fig. 597. The exhaust gas from cylinder No. 5 is brought to an elbow bolted to one end of the air heater. At the other end studs are arranged for a standard flange fitted with a pipe to discharge the exhaust gas into a manifold or into the slipstream as desired. The exhaust connections are made with elbows of steel tubing welded to the exhaust flanges, a straight piece of flexible metal tubing being secured to the elbows by hose clamps. Copper and asbestos gaskets fit over the cylinder exhaust port and the inlet and outlet exhaust ports of the heater. Above the heating elements is a valve which is controlled by a separate lever in the cockpit When open, this valve will shut off the intake air from the heater and will open another port to admit unheated air to the carburetor.

Hand Starter.—The crankcase rear section is provided with a standard Army-Navy starter pad so any one of several types of starters can be supplied at the option of the customer. The engine starter dog is located on the rear of the crankshaft extension. Information on the operation and maintenance of the Aeromarine Inertia Starter will be found in the special chapter on installation.

Generator Drive.—The rear section is provided with a standard Army E3 generator drive. This drive rotates at one and one-half crankshaft speed in clockwise direction. (Observe facing open drive.) On the upper ends of the vertical drive shafts in the rear section are two Type E4 gun synchronizers. These rotate at crankshaft speed and in opposite direction. A dual tachometer drive is located on the oil pump cover and rotates at one-half crankshaft speed in clockwise direction. (Observe facing the drive.)

Propeller Hub.—The crankshaft is designed to fit a short propeller hub with metal blades. The instructions furnished by the Standard Steel Propeller Co. in the chapter on installation, give complete information on the assembly and disassembly of the propeller and hub.

TABLE OF SPECIFICATIONS

For Wright Cyclone Engine, Model R1750

Type	Radial, Air-cooled
Number of cylinders	9
Bore	6.000 in.
Stroke	6.875 in.
Piston displacement	1750 cu. in.
Compression ratio	5.0:1
Normal speed in revolutions per minute	1900 r.p.m.

Normal brake horsepower at sea level and at normal r.p.m. with aviation gasoline	535 b. hp.
Guaranteed brake horsepower at sea level and at normal r.p.m. with aviation gasoline	525 b. hp.
Direction of rotation of crankshaft, looking at propeller end of engine	Counter-clockwise
Average weight of engines	760 lbs.
Center of gravity, distance forward of rear face of mounting bosses on center line of crankshaft (without propeller hub)	5.95 in.
Diameter of mounting bolt circle	23⅛ in.
Number of mounting bolts	9
Size of mounting bolts	$\frac{7}{16}$ in. dia.
Overall dimensions	
Length	40⅝ in.
Diameter	53[illegible] in.
Mounting plate forward	27⅞ in.

Ignition:

Magneto type	Scintilla V-AG-9D
Direction of rotation of magnetos, looking at drive-coupling end	Counter-clockwise
Magneto speed	1⅛ Crankshaft
Magneto breaker point gap	.012 in.
Sparkplug gap	.015 in. (B.G.)
Spark occurs, in crankshaft degrees, before top dead center	30°

Valves and Timing:

Intake opens	25° b.t.c.
Intake closes	60° a.b.c.
Exhaust opens	80° b.b.c.
Exhaust closes	25° a.t.c.
Intake remains open, in crankshaft degrees	265°
Exhaust remains open, in crankshaft degrees	285°
Valve lift	$\frac{3}{16}$″
Valve-tappet clearance, both valves, for timing and running	.050″

Fuel System:

Carburetor type	Stromberg NA-Y7A
Guaranteed fuel consumption at guaranteed power and normal speed, pounds per brake horsepower hour	.55 lb. p.b. hp. hr.
Fuel pressure, pounds per square inch	2-4 lb. p. sq. in.

Lubrication System:

Guaranteed oil consumption, pounds per brake horsepower hour	.035 lb. p.b. hp. hr.
Oil Pressure, pounds per square inch	
At 300 to 500 r.p.m.	20 lb. p. sq. in.
At normal r.p.m. and recommended oil temperature	45 to 65 lb. p. sq. in.
Quantity of oil circulated per minute at normal pressure, speed and temperature	26 lbs.
Minimum safe quantity of oil in whole system	4 gal.
Maximum permissible outlet temperature oil under worst conditions	180° F.
Desired maximum oil outlet temperature in normal operation	140° F.
Speed of oil pump	1¼ x Crankshaft (1¾)
Direction of rotation of oil pump, looking at driven end of oil-pump shaft	Counter-clockwise

Hose connections required between engine and lubricating system:	
Inside diameter	1 in.
Number of pieces	2

Supercharger:

Speed of impeller	8 x Crankshaft

Starting and Normal Operation.—Before starting the engine for the first time, check the following items: 1. Check over all nuts and bolts on both the engine and the mount and see that they are tight and properly locked. 2. Check the propeller hub nuts to be sure that they are tight and cottered 3 Lubricate the valve gear with the Alemite gun. 4. Fill the oil tank with an ample quantity of oil for the run (minimum quantity four gallons) and see that all lines are open. 5. Fill the gasoline tank with the proper grade of gasoline. 6. Operate the throttle, mixture, and heater controls and inspect the levers on the carburetor and heater to make sure that they hit the stop on both ends of the travel without restriction 7. Operate the spark-advance control and inspect for full operation of the lever. 8 See that the tachometer and oil pressure gauge are properly connected to the engine and that the oil temperature thermometer bulb is in place. 9 Turn the engine over by hand to see that everything is clear.

10. See that the priming line, pump and valve are properly connected and in working order 11. Open the cocks in the gas line and operate the hand pump if supplied. Do not pump up more pressure than the fuel pressure gauge can indicate. See that gasoline is supplied to the carburetor and that all lines are tight. See that the carburetor does not drip gas excessively. 12. See that ground wires are connected to the magnetos.

Starting.—The items in the foregoing paragraph should all be checked the first time the engine is started. It is recommended that Items 4, 5, 6, 7, 11 and 12 be checked **every** time the engine is started. After the pre-starting inspection has been completed, the engine is ready to start and should be handled as follows:

1. Give the engine several strokes of the priming pump. Experience is necessary to determine the proper amount of prime for each engine About seven or eight strokes of the Lunkenheimer pump are usually necessary. Excessive priming has a tendency to wash the oil off the cylinder walls and to cause scoring or seizing of the sleeves and pistons. In cold weather the engine requires more priming than in warm weather. A hot engine does not ordinarily require priming. 2. Turn the engine over a number of times with the throttle closed to suck the gas into the cylinders 3. Set the throttle lever to the closed position and the mixture control to "Full Rich." The air heater valve should also be closed except in very warm weather. As a rule, easier starting will be obtained with the spark control at approximately full advance, but if the engine should exhibit a tendency to kick back, it may be necessary to retard the spark half way. This procedure is almost always necessary in cold weather.

4. Operate the starter and allow the engine to turn over a full revolution Then turn the ignition switch to the start position and operate the booster if one is being used. 5. As soon as the engine fires, open the throttle slowly

to the position where the tachometer will indicate about 600 r.p.m. and then advance the spark. The throttle is kept closed in starting to bring the idle system of the carburetor into operation when the engine is turned over by the starter. If the throttle is opened rapidly when the engine starts to fire the idle system discharge may be cut off. Open the throttle slowly. 6. If the engine fails to start after several attempts prime again and repeat. If the engine is overprimed as indicated by the dripping of gas from the carburetor, the throttle should be opened wide and the engine turned backward several revolutions by hand. Be sure the ignition switch is off. 7. In extremely cold weather the oil should be heated before filling the oil tank if the plane has been standing in an unheated hangar. If the engine fails to start after a reasonable number of attempts, consult the instructions that follow on engine trouble to ascertain the possible cause.

Ground Test.—When the engine starts, the oil gauge should be watched for pressure. If the pressure fails to rise within one minute, the engine should be shut down and an investigation made. After the gauge indicates oil pressure, the engine should be run at 600 to 800 r.p.m. for two minutes or more and the throttle then opened slowly to 1,000 r.p.m., where it should be held until the oil-outlet temperature has come up to at least 85 degrees Fahrenheit (30 degrees Centigrade). In cold weather it may be necessary to run the engine at a higher speed to bring the temperature up to the desired figure. The speed may then be increased slowly to full throttle. The mixture control should be leaned out until the engine is turning at the maximum r.p.m. This may occur in the "Full Rich" position. Observe the r.p.m., oil pressure and oil temperature. With the mixture control set for the maximum r.p.m. check the functioning of the engine when running on one magneto at a time. The speed should not drop more than 75 r.p.m. on either magneto. With the mixture control set in the "Full Rich" position, pull the throttle back until the engine is idling and then open it quickly about half way. The acceleration should be smooth and rapid. If all valves appear normal and the operation is smooth, the engine is then ready for flight. It should be remembered that the engine receives very poor cooling while on the ground and prolonged running at full throttle should be avoided. Always head the plane into the wind when running the engine on the ground. Pull the mixture control lever back to the "Full Rich" position before taking off.

Flight Operation.—As soon as the desired altitude has been reached and the engine has been throttled back to cruising speed the mixture control and the air heater valve should be adjusted to give the best fuel economy. First set the throttle so the engine is turning about 30 r.p.m. faster than is desired and then move the mixture control lever towards the "Lean" position until the engine has slowed down to the desired speed. The heater valve should then be adjusted. The best position for the heater valve varies, of course, with the condition of the atmosphere. In moderate weather it is possible to find an intermediate position for the valve so that the maximum engine speed for a given throttle opening can be obtained without the formation of ice. In hot, dry weather the best results may be obtained with the valve wide open, while in very damp, cold weather it may be necessary to keep the valve fully closed to secure the full heating effect.

When the heater valve has been adjusted it may be possible to lean out the mixture a little more. Roughness at part throttle is an indication of insufficient heat and may usually be cured by increasing the amount of heated air. When in doubt always use the air heater.

The instruments should be noted at frequent intervals to see that the powerplant is functioning properly. The engine should be operated to keep within the following limits: Oil pressure, 45 to 65 pounds per square inch. Outlet oil temperature, not over 180 degrees Fahrenheit (82 degrees Centigrade). Fuel pressure, two and four pounds per square inch. If the oil pressure falls below 35 pounds, an immediate landing should be made and the cause of the trouble located and removed. It should be remembered that, with the oil system used on the Cyclone, the pressure naturally decreases with the engine speed and due allowance for variation in the engine r.p.m. should be made.

It is not so serious when the oil pressure exceeds the high limit; but it should be corrected at the end of the flight. This correction can generally be accomplished by adjusting the relief valve. High oil temperature, when not caused by atmospheric condition, may be a sign of trouble in the engine. If the outlet oil temperature rises above 180 degrees Fahrenheit a landing should be made as soon as possible, and the cause of the rise determined and corrected.

Landing.—When the throttle is pulled back in making a landing the mixture control lever should always be set back to the full rich position. This will insure good acceleration if it becomes necessary to open the throttle again. Because of the rapid heating and cooling rate of air-cooled engines, a hot engine should never be shut down rapidly, except in emergencies, as such treatment has a tendency to warp the valves After a plane has landed and taxied to the line, the throttle should be slowly closed to 600 to 700 r.p.m., and the gasoline supply shut off. The engine should be allowed to run in this manner until the fuel supply fails. If this plan of operation is followed regularly, the time between overhauls will be greatly increased.

Fuel Specifications.—The fuel used should be of the type known as Grade B domestic aviation gasoline, as the use of other fuels is apt to lead to unsatisfactory operation and serious damage to the engine. The manufacturer will assume no responsibility for the engine's performance when other fuels are used. In case of emergency, when approved gasoline is not available, benzol gas, ethyl gas or high test automobile gasoline should be used. The engine should then be operated at reduced throttle with mixture control in the full rich position. Gasoline from California base crudes is much superior to gasoline from the mid-continent and Eastern crudes for use in Cyclone engines.

The following specifications correspond to the Navy Department Specification No. 7G1b of Dec. 1, 1924, for Grade B domestic aviation gasoline. Grade B domestic aviation gasoline shall conform to the following requirements:

1. The gasoline shall be free from water and suspended matter.
2. **Color**—The color shall not be darker than No. 25 Saybolt.
3. **Doctor test**—The doctor test shall be negative.

4. **Corrosion test**—One hundred cubic centimeters of the gasoline shall cause no gray or black corrosion and the amount of deposit, when evaporated in a polished copper dish, shall not exceed three milligrams.
5. **Distillation range**—The temperature limits are as follows:
   When five per cent of the sample has been recovered in the graduated receiver, the thermometer shall read not more than 75 degrees Centigrade (167 degrees Fahrenheit), nor less than 50 degrees Centigrade (122 degrees Fahrenheit).
   When 50 per cent has been recovered in the receiver, the thermometer shall not read more than 105 degrees Centigrade (221 degrees Fahrenheit).
   When 90 per cent has been recovered in the receiver, the thermometer shall not read more than 155 degrees Centigrade (311 degrees Fahrenheit)
   When 96 per cent has been recovered in the receiver, the thermometer shall not read more than 175 degrees Centigrade (347 degrees Fahrenheit).

The end point shall not be higher than 190 degrees Centigrade (374 degrees Fahrenheit).

At least 96 per cent shall be recovered as distillate in the receiver from the distillation.

The distillation loss shall not exceed two per cent when the residue in the flask is cooled and added to the distillate in the receiver.

6. **Acidity**—The residue remaining in the flask after the distillation has been completed, shall not show an acid reaction.
7. Sulphur content shall not be over .10 per cent.

Oil Specifications.—Lubricating oils for use in Wright engines must conform to the following specifications:

1. **Flash point**— Method 110.32. The flash point shall not be lower than 400 degrees Fahrenheit.
2. **Viscosity**—Method 30.41. The viscosity, for summer use, shall be 90 to 105 sec. at 210 degrees Fahrenheit, and shall be 75 to 85 sec. at 210 degrees Fahrenheit for use in winter.
3. **Pour points**—Method 20.12. The pour point for summer use shall be less than 45 degrees Fahrenheit and shall be less than fifteen degrees Fahrenheit for use in winter.
4. **Acidity**—Method 510.31. To neutralize one gram of oil, not more than .10 milligram of potassium hydroxide shall be required.
5. **Emulsion test**—Method 320.21. The oil shall separate completely in one hour from an emulsion with distilled water at a temperature of 180 degrees Fahrenheit.
6. **Carbon residue**—Method 500.12. The carbon residue shall not exceed 2.5 per cent.
7. **Precipitation number**—Method 310.1. The precipitation number shall not be greater than five-tenths.
8. The oil shall be derived from a petroleum base and shall be free from fatty oils, resins, soap and other compounds not derived from petroleums.

Tests—All tests shall be made in accordance with "Methods for Testing Lubricants and Liquid Fuels" contained in Technical Paper No. 323B, Bureau of Mines. The method numbers given above refer to this paper. Copies of the paper may be obtained by application to the Superintendent of Documents, Government Printing Office, Washington, D. C.

Engine Troubles.—Determining the causes of engine trouble is at times rather involved on account of the number of sources to which a given symptom may be attributed. The best method of "trouble shooting" is to first decide on the possible causes and then eliminate them one by one, starting with the most probable. This table of the commonest troubles and their causes is submitted to the service men with the object of reducing wasted time and increasing the reliability of the engine.

Failure of Engine to Start.—If the engine fails to start, it may be due to any one of the following conditions: 1. Lack of Fuel—Examine the fuel supply, shut-off cocks, traps, strainers, and hose connections. 2. Under Priming or Over Priming—See instructions on starting. 3. Booster Magneto Defective—Examine and test the starting magneto. 4. Throttle Opening Incorrect—The throttle should be kept closed until the engine starts to fire and should then be opened slowly to the position where the tachometer will indicate about 600 r.p.m. 5. Defective Ignition Wire—Examine ignition wiring for wear, breaks and incorrect connections. 6. Dirty Sparkplugs—Check the sparkplugs for proper functioning. Clean and set gaps (B.G., .015 inch). 7. Incorrect Valve-Tappet Clearance—Check the valve-tappet clearance. 8. Incorrect Timing—Check the valve and ignition timing. 9. Water in Carburetor—Open the strainer chamber draincock and remove the two accelerating well plugs to drain off the gasoline and water. 10. Cold Oil—With the ignition switches off, turn the engine over by hand. If it is very stiff, it will be necessary to drain and heat the oil before starting. 11. Magneto Breaker Points—See that the magneto breaker points are clean and have the proper gap of .012 inch. Test the spark delivered by the magneto. 12. Miscellaneous—Examine the engine carefully for unusual conditions, turning over slowly by hand.

Low Oil Pressure.—Low oil pressure or none at all may result from the following causes: 1. Lack of Priming—Disconnect the oil suction line and fill the pump with oil. Turn the engine over by hand until the oil is sucked into the pump. Check the oil supply. 2. Leak in Suction Lines—Examine the oil-suction lines for air leaks. 3. Dirt in Oil Screen—Remove and clean the oil strainer. 4. Improper Setting of Relief Valve—Remove the cap over the idle oil-pressure adjusting screw, loosen the locknut and turn in on the screw until a pressure of twenty pounds is obtained at idling speed. If this adjustment does not give the recommended pressure at rated speed, remove the cap, loosen the locknut and turn up on the main oil-pressure adjusting screw until a minimum of 45 pounds pressure at rated speed is secured. If this pressure is not reached until the screw is all the way, or nearly all the way down, the trouble lies somewhere else. Adjustment of the pressure may be made with the engine running and should be made when the oil is hot. 5. Excessive Bearing Clearance—A bearing may be worn enough to cut down the pressure, in which case an overhaul will be necessary.

Oil Accumulation in Crankcase.—The filling of the crankcase with oil is usually caused by lack of priming in the discharge pump. Disconnect the main discharge line from the engine and put on a two-foot length of garden hose. While turning the engine backward, feed oil into this hose until a quart or so has been sucked in. Check the oil pumps, strainers and lines for failures or stoppages. Oil may accumulate in the crankcase until the scavenging pumps are primed, in which case the trouble will be rectified as soon as the pumps start operating. This may take several minutes.

Low Power and Uneven Running.—The full-throttle speed of the engine will vary by 75 to 100 r.p m. under different atmospheric conditions, the greatest variation occurring with the changing of the plane's angular position with regard to the wind. It will also vary considerably with the condition of the propeller. The engine should not be considered low on power, therefore, unless the drop in speed is excessive under similar conditions. Low power and uneven running may be traced to any of the following causes: 1. Rich or Lean Mixture—Make sure the mixture control lever is in the best position. 2 Leaks in Induction System—Examine the intake pipes for cracks and for leaks at the cylinder and crankcase connections. Examine the carburetor and intake manifold flanges for tightness. 3. Sparkplugs—See that all the sparkplugs are clean, that they have the proper clearance and that they are not burned. 4. Valve and Valve-Gear Trouble—Check the valve-tappet clearance, springs, washers, rocker arms, and push rods. See that the valves are not sticking. 5. Poor Fuel—Make sure the fuel being used is a good grade of domestic aviation gasoline and that it flows freely to the carburetor. Fuel which causes detonation should not be used This condition can be detected by adding benzol or ethyl fluid to the gasoline being used and noting the improvement in the performance of the engine. Be sure that the sparkplugs are in good condition for this test. 6 Magneto Breaker Points—See that the magneto breaker points are clean and have the proper gap of .012 inch. Check the operation of the magnetos

7. Engine Overheating—This condition may be caused by items 1, 2, 3, and 5 under the head of Low Power. It is easily recognized by the fact that the engine will run at normal speed just after idling and will then slowly fall off. Continued running of an engine exhibiting this symptom is liable to cause considerable damage, so an investigation of the cause should be started immediately. Other causes include improper cowling, excessive air temperature, thin oil, insufficient oil cooling, and poorly designed exhaust manifold.

Excessive Oil Temperature.—This condition may result from: 1. Insufficient oil cooling. 2. Insufficient oil supply—There should be at least four gallons of oil in the system. 3. Low grade oil—See that the oil being used is up to specification. 4. Suction pump failing to scavenge the oil properly from the crankcase.—Examine all oil lines for leaks. 5. Overheated bearing—If the trouble is not found after an investigation of 1, 2 and 3, a bearing may be overheating, in which case a disassembly will be necessary.

Carburetor Leakage.—Because of the fire hazard, the engine should not

be run if the carburetor leaks gasoline excessively. The leakage may be caused by: 1. Leaky float. 2. Stuck float. 3. Poor seating of the needle valve. 4. Wear of the float fulcrum pin In any case, the carburetor should be removed and checked over. If the float has been leaking, the gasoline should be removed, the hole soldered, and the float immersed in hot water to test for tightness. Leakage by the needle valve can be remedied by holding the valve in position on the seat and tapping smartly with a small hammer.

Cold Weather Precautions.—In extremely cold weather it will be necessary to preheat the oil before starting if a heated hangar is not available. A great deal of time can be saved by draining the oil from the tanks as soon as operations for the day are concluded and before the oil has cooled off. If left in the tank over night, the oil may become so viscous as to require considerable time to drain. In cold weather it is also advisable to have some sort of lagging on the external oil lines to and from the tank. This will result in higher oil temperature at cruising speed and will decrease the danger of stoppage due to congealed oil. A layer of asbestos cord, shellacked and then wrapped with friction tape provides very good insulation. Lacking asbestos, several layers of ordinary packing cord can be used. A large sized oil-pressure gauge line is essential in cold weather to obtain an immediate indication of any pressure variation in the engine.

Inspection Routine.—In order to obtain maximum reliability and service from engines a regular schedule of inspection and overhauls should be maintained. Serious failures very often arise from minor causes which a few minutes' inspection could have averted. The following schedule is suggested, this being practically the same as recommended previously for the "Whirlwind" engines.

Daily Inspection.— Every flying day the following inspection should be made: 1. Are the sparkplugs tight? 2. Grease the rocker arm shafts with the Alemite gun using a No. 3 grease free from graphite or other compounds which will cause caking on the exhaust valve stems. 3 Are ignition terminals secure to wires and plugs and is insulation on wires intact? 4. Is compression normal? 5. Are carburetor and carburetor manifold tight at securing flanges? 6. Are fuel tanks filled? 7. Is oil tank filled? 8. Are magneto ground wires secure? 9. Are throttle, mixture and magneto controls free throughout their range? 10. What is full throttle r.p.m.? 11. Is engine operation good on either magneto? 12. Are values of oil pressure and temperature normal? 13. What is gasoline pressure? (Should be two-four pounds per square inch) 14. Are the air heater connections tight? Make sure there are no leaks between the coils of the flexible tubing as these are apt to grow into breaks very rapidly. Twist the tubing to tighten up loose coils.

Twenty Hours.—After every twenty hours of flight the engine should be inspected as follows: 1. Remove the rocker box covers and make a check of the amount of motion of the various parts. If the tappet clearance seems normal it should not be disturbed. If any part seems to have too much motion, or if the tappet clearance is excessive, the rocker arm and push rod should be removed and the cause determined. Check the offending part against the maximum allowable clearance as indicated in the charts in this

chapter (Figs. 608 to 612 inc.) and replaced if this is exceeded, and if in the opinion of the operator it seems advisable. 2. Are sparkplug points clean and are gaps set at proper clearance? (.015 inch for B. G. plugs.) 3. Are nuts on inlet pipe upper flanges tight? 4. Are inlet pipe packing nuts tight? 5. Are cylinder hold down nuts tight and are Palnuts in place? 6. Are fuel strainers clean? 7. Are fuel lines and connections secure and free from leaks? 8. Is lock on gasoline pump pressure adjusting screw secure? 9. Are oil strainers clean?

10. Drain the oil from the tanks and lines and flush with kerosene until perfectly clean. (Do not use kerosene inside the engine.) Replace the lines and put four gallons of clean oil in tank. Run the engine for twenty minutes and then drain out all the oil again. Fill the tank with clean oil. Great care should be taken to see that all the oil lines are replaced properly and there are no air leaks. Small air leaks are apt to interfere seriously with the proper functioning of the lubricating system.

11. Are engine mounting bolts tight? 12. Does each magneto get full advance when operated from cockpit? 13. Are magneto breaker points clean and gaps set at .012 inch? 14. Are magneto couplings in good condition? 15. Put four drops of medium machine oil in rear magneto oil holes. Fill front holes. 16. Lubricate the carburetor throttle shaft bearings and all parts of the control mechanism where friction is present. 17. Are propeller hub lock nuts tight?

18. The rocker box housing should have at least .031 inch clearance over the pad on the top of the cylinder. This is set on a new engine and will never decrease unless some part is stretching or wearing. The push rod housings should be tight at all times when the engine is hot and should be checked by shaking the top ends of the housings. If any housing is loose the clearance should be reset to .031 inch to .035 inch by first tapping the rear end of the rocker box with a rawhide hammer and then turning the push rod housing adjusting nut with tool WA-256 to obtain the correct value. This will alter the valve clearance which should then be readjusted. A slight amount of push rod housing looseness on a cold engine is permissible and should not be disturbed. It is advisable to run the engine at part throttle for at least ¼ or ½ hour twice a week in order to keep the inferior parts flushed with oil. This will prevent the vapor due to condensation in the crankcase from rusting steel parts.

Overhaul.—It is suggested that the compression, as noted in item 11 of the dail inspection, be checked very carefully on each cylinder. As soon as one is found to be low it should be removed, the valves tested for leakage and the piston rings checked for tension. The valves should be ground and the piston rings replaced when necessary. In this manner the engine can be kept up to power and speed. It is sometimes very difficult to distinguish between a valve which is leaking and one which is being held open by a bit of dirt or carbon on the seat. The only way to check this out is to run the engine for several minutes and then try out the compression again. The length of the periods between complete overhauls varies with the severity of the service and rests largely with the judgment of the operator. Under normal conditions the Cyclone engines will operate satisfactorily for 200 to 300 hours before complete disassembly and overhaul become necessary.

Disassembly.—When the condition of the engine seems to warrant a general overhauling, it should be removed from the ship and sent to the overhaul depot. This should be a clean, light shop, provided with a bench lathe, drill press, arbor press, buffing wheel, engine stand, and a complete set of the overhaul tools as furnished by the engine makers. The best overhaul stand is the type which permits rotating the engine to any desired angle as previously described in connection with overhauling the Wright "Whirlwind" engines. The mechanics are then able to do each part of the work with the engine in the most convenient position. If this type of stand is not available the lower half of the engine shipping box can be used when it is desired to have the engine in the upright position and a stand of the type shown in photographs showing removal of front cover can be constructed to hold it in the inverted position. It has been assumed in the text that the rotating type of stand is not available.

Fig. 604.—Method of Grinding "Cyclone" Valves Shown at A and Method of Removing Valve Stem Collar Lock Shown at B.

Inspection Bench.—As each part is removed, it should be washed in gasoline and placed on the inspection bench. The bench should be located near the disassembly floor and where it will receive a good supply of light. A drop light is necessary for inspecting the cylinder bores and valve seats.

A service tool kit is furnished by the manufacturer with each engine. This outfit contains tools sufficient for the general servicing of the engine and should be carried in the plane for use in emergencies and is very similar to that furnished with "Whirlwind" engines. For completely disassembling and reconditioning the engine, a number of special tools are absolutely necessary. A repair depot handling any great number of engines should be equipped with a complete set of these tools, the outfits shown at Figs. 575 and 576 in the preceding chapter are typical.

Disassembly.—The following instructions for disassembly are presented in as great detail as space permits. In the event that any point seems obscure it is suggested that the sectional views of the engine shown at Figs.

598 and 599 be consulted. It will also be necessary to consult the assembly drawings from time to time, as references are frequently made by part number instead of part name. This was done to avoid confusion due to the similarity and complexity of some of the part names.

Cylinders.—As soon as the engine is conveniently set up, the work of disassembling can be started. Using tool WA-328, loosen the thrust-bearing nut. This nut should not be removed but should be loosened while the sparkplugs are still in the engine. Remove all sparkplugs and then the intake pipes. Remove the three cap-screws at the intake pipe flanges and,

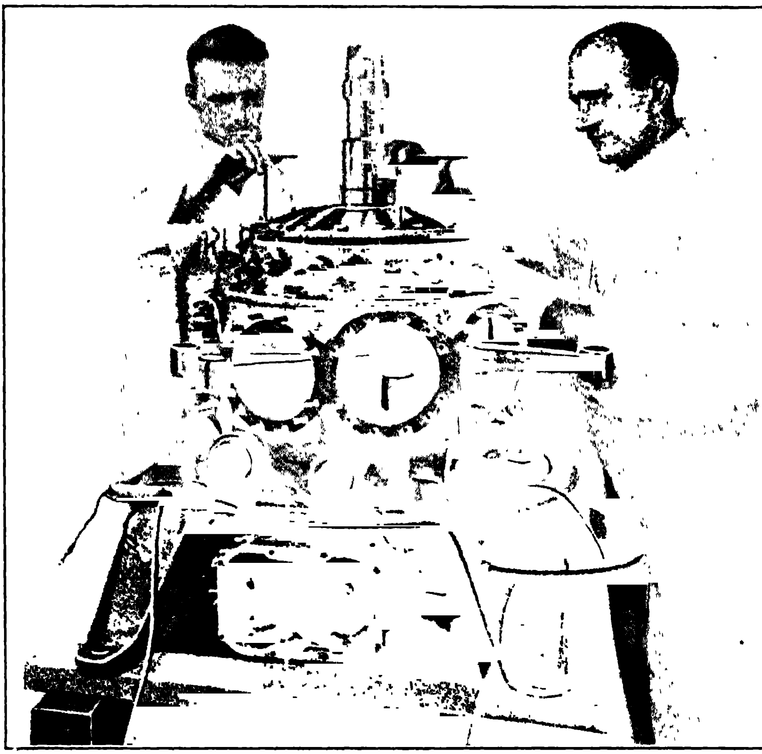


Fig. 605.—Removing Front Cover of Wright "Cyclone" Engine.

using tool WA-299, loosen the packing nuts at the crankcase ends of the pipes. Detach the ignition wires from the clips on the cylinder heads and intake pipes, and remove the intake pipes. It is advisable to leave the No. 7 cylinder until the last to prevent the rods from slapping about.

Set the piston of the first cylinder to be removed on the approximate top center and remove the cylinder hold-down nuts. Remove the push-rod housing lower stud nuts with tool WA-319 and pull off the cylinder, taking care that the piston does not swing over against the adjacent cylinder. Care should also be taken not to drop the push rods when the cylinder is removed as they will be loose in their housings.

As soon as a cylinder has been removed, the piston should also be taken off to avoid injury in subsequent operations. I [illegible] wristpin out or tap it out with fiber drift WA-339. In this operation care should be taken to avoid flattening the wristpin plug as this is liable to lead to scoring of the cylinder walls. Remove the rest of the cylinders and pistons in the same fashion.

To disassemble the valve gear, set the cylinder on a wooden block so shaped that it will hold the valves in place. Remove the rocker-box covers, the cotter pins, nuts, washers, rocker-arm pins, and rocker arms. Slip a smooth piece of steel rod through the rocker-arm pin holes, and, using valve-spring compressor WA-300, compress the valve springs as shown at Fig. 604 B. As soon as the split locks have been removed, the springs and retaining washers are free and can be taken off. Remove the cotter pins, nuts, washers, and the rear spring and remove the rocker boxes and push-rod housings. The washer under the rear spring is apt to be forgotten and lost. Remove the wire circlets from the valve stems and take the cylinder off the block, holding the valves so that they will not fall through. Remove the valves, taking care that they do not touch and nick the cylinder walls. To remove the push-rod housings, loosen the locknuts and back off on the adjusting nuts until free.

Front Section.—Remove the thrust-bearing nut and the hold-down nuts on the front section. Remove the brass plugs in the three puller holes in the front section and insert the three pullers, WA-310. Turn down evenly on all three until the thrust bearing is free on the shaft and the front cover can be carefully removed. Take off the six hold-down nuts and the thrust-bearing housing cover. Lay the section on a bench with the front up and using a small brass drift, tap the inside upper corner of the bearing lightly until it drops out of the housing. The housing can be removed, if necessary, using two of the pullers WA-310 as shown at Fig. 605.

Intermediate Section.—Push back all the cam follower rollers until they are clear of the cams and remove the spacer and cam bearing 21,134. Lift off the cam, taking care not to strike the babbitted bearing against the crankshaft, and remove the camdrive gear 20,366. To remove the cam followers or tappets, take off the circlets at the upper ends and push them out towards the inside. The rollers and pins are loose and will fall out if they are not held in place. The guides may be removed toward the outside. The followers and guides are a selective fit and must be kept together. It is therefore advisable to re-assemble them immediately after they have been removed.

Remove the cotter pin and nut and lift the cam gear and pinion off the pin. Remove the hold-down nuts and the puller hole plugs and insert the three pullers WA-310 in the holes provided for that purpose in the outer edge of the intermediate section. Turn down slowly and evenly on all three and lift off the intermediate section. Invert the section, remove the cotter pin and the large nut 20,361, using wrench WA-327. Then take a piece of half-inch round bar stock and, inserting it in the hollow pin from the rear, drive out the camdrive pinion pin. Be careful not to injure the threads. This pin is a very close fit and should not be removed unless it is known to be defective.

Articulated Rods.—Cut the safety wires and remove the screws and knuckle-pin lockplates. Do not lose the copper washers under the screw heads. In removing the knuckle pins, keep the round part of the crank-cheek adjacent to the pin being removed, in order to insure ample clearance. Using puller WA-323, remove the knuckle pins and take out the articulated rods. Be sure to screw the puller all the way into the knuckle pins to avoid stripping the threads when force is applied. This operation is shown at Fig. 606.

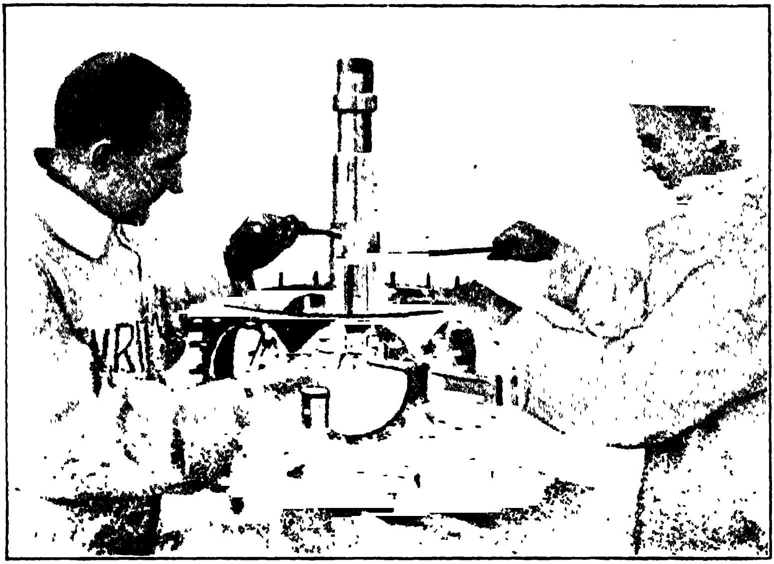


Fig. 606.—Removing a Knuckle Pin from Wright "Cyclone" Engine Assembly.

Crankshaft and Master Rod.—Turn the crankshaft until the counter weights are directly over the shank of the master rod and place the hoisting eye WA-337 on the end of the crankshaft. Using the chain hoist, lift up the shaft and rock it slightly until it is loose in the case. Then tip it until the master rod can be withdrawn from the No. 7 cylinder opening and lift the whole assembly out of the crankcase. Place the front counterweight in a vise, the jaws of which are faced with soft copper or brass, and remove the cotter pin from the clamp screw. Using tool WA-340, remove the clamp screw and washer. Insert wedge WA-316 in the slot in the rear section of the crankshaft and tap down until enough clearance is obtained to slide the rear section off the crankpin. The master rod can then be pulled off the crankpin. It is not usually necessary to remove the front bearing sleeve; but if this should be required, it can be accomplished by inserting a pointed brass drift in the oil hole and tapping it forward. To remove the rear bearing, which is also usually unnecessary, place the rear section in a vise, remove the cotter pin and back off the spanner nut with tool WA-338. Lift off the slinger and tap the roller bearing off toward the rear.

Fig. 607.—Method of Removing Supercharger and Generator Driveshaft of Wright "Cyclone" Engine Shown at A. Method of Removing Supercharger Section Shown at B.

Rear Section.—Lift the case by the rear hoisting eyes and set it down with the rear section up. Remove the carburetor, using wrench WA-314. Disconnect the magneto-control rods at the control shaft end, disengage the magneto couplings and remove the magnetos. To disengage the couplings first remove the lock wires and then push the couplings towards the magnetos, rotating them slightly to catch the teeth of the coupling gears behind the teeth of the gears on the magnetos. Remove the generator by taking off the four hold-down nuts on the flange. Remove the hold-down nuts and the five induction passage seal screws. Using the three pullers WA-310, lift off the rear section. The oil pump is removed by taking off the hold-down nuts and using one of the three pullers WA-310 in the tapped hole provided.

Disassemble the Oil Pump as Follows.—Remove the four nuts and washers on the four long studs and the three screws holding the tachometer drive to the outer face of the pump. Remove the tachometer drive and, holding the pump in the hand, tap off the front cover. The four studs and the two dowels are held in this section and will come out with the cover. The gears on the idler shaft 20,950 are free and can be slipped off while those on the driveshaft 21,023 are keyed on and must be worked off with a screwdriver. Remove the two gears exposed when the front cover is taken off and also the key. Tap off the other sections, removing each pair of gears as they are exposed. To remove the tachometer driveshaft, unscrew the large hexagonal nut and withdraw the shaft and gear. The fuel pump can be taken off after the removal of the four hold-down nuts. The drive gear and bearing can then be removed by tapping from the inside. Slip off the lockring at the outer end to remove the drive gear. Remove the nuts and washers on the synchronizer studs, and tapping upward on the inside, loosen and remove the synchronizers (or covers) and the vertical driveshafts.

To remove the magneto driveshafts, hold the coupling gear and remove the cotter pin and nut on the inner end. Drive the shafts through the drive gears toward the outside. Tap the generator drive out toward the rear and withdraw the generator-drive gear from the bushing in the rear section. To disassemble the generator drive, remove the lockring and nut from the rear end and withdraw the shaft. To remove the coupling gear from the magneto, hold the gear lightly in a vise and take off the nut with a socket wrench. Then remove the gear with puller WA-10. Removing this gear without the puller is very difficult and generally results in injury to the magneto shaft.

Remove the two nuts holding down the bearing cap and with a lead hammer tap the supercharger and generator driveshaft until it is free and can be taken out as shown at Fig. 607 A. Remove the cotter pin and nut on the forward end and tap the gears off the splined shaft. These gears need not be disassembled unless they are known to be defective.

Remove the six nuts holding the impeller-drive bearing support 21,149 in place and pull out the assembly. This group need not be disassembled unless it is desired to replace some part. In that case, proceed as follows: Remove the cotter pin, securing the nut 20,565, and with tool WA-311, back

off on the nut. The crankshaft extension 20,495 can then be tapped out toward the rear. By removing the six fillister-head screws, the crankshaft-extension bearing and housing can be removed and the bearing tapped out of the housing. If either the supercharger and generator drive gear 21,255, or the accessory drive gear 20,490, is to be replaced, the rivets must be drilled out and the assembly re-rivetted. Before heading over the rivets clamp the parts securely together. When completed, set the assembly up in a lathe and check with an indicator. All of the serial numbers given are the maker's part numbers.

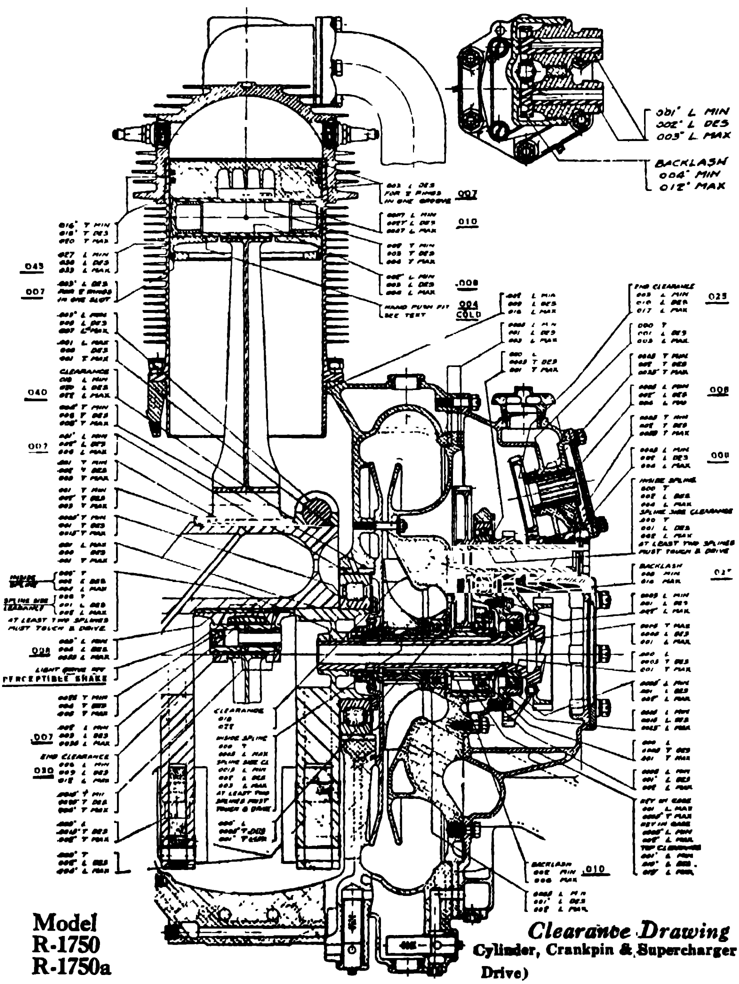


Fig. 608.—Clearance Drawing Showing Wright "Cyclone" Cylinder, Crankpin and Supercharger Drive.

Supercharger Section.—There are two studs and nuts holding the supercharger section to the main section. These nuts should be removed with a long socket wrench WA-313 and by means of pullers WA-310, the supercharger section should be removed as shown at Fig 607 B. To remove the impeller for inspection proceed as follows: With a sharp screwdriver tap back the metal of the impeller-retaining nut 20,684 where the setscrew 20,920 has been locked in with a center punch. This should be done carefully in order to avoid stripping the screw threads. With a small screwdriver which just fits the screw slot remove the setscrew.

Set the section up in a vise, the jaws of which are faced with soft copper or brass, holding it by the flange at one side. Hold the impeller-shaft rear-bearing nut 20,484 with tool WA-309, loosen the impeller retaining nut 20,684 and remove. Screw puller WA-324 into the inside thread of the impeller and withdraw it from the shaft. Still holding the supercharger in the vise, remove the cotter pin and with tool WA-356 back off nut 20,459. Tap the impeller-shaft bearing cage out of the supercharger section and set it in a vise, gripping it by the splined shaft. As this shaft is hollow, care should be taken not to distort it by too much pressure. Remove the cotter pin and with tool WA-309, back off the rear bearing nut 20,484. The impeller shaft and the rear bearing can then be tapped out toward the rear of the cage and the bearing tapped off the shaft.

As a convenient method of holding the cage during the next operation, put it back in the supercharger section, not forgetting the key. Remove the cotter pin and using tool WA-326, back off on the front bearing nut, 20,466 The front bearing can then be tapped out of the cage. As there are several slingers in this assembly which are almost alike, special notice should be taken of their arrangement in order to prevent mistakes in assembly.

Oil Seal.—Remove the two spacers 21,228 from the studs and take out the six flat-head screws which hold the oil seal to the rear wall of the crankcase. Reach in through the intake ports with two long screwdrivers and loosen the oil seal plate until it can be lifted off over the studs. Take off the circlet 21,123 and remove the impeller oil-retainer bushing 21,121 from the oil-seal assembly.

Crankcase.—To facilitate cleaning the oil passages in the crankcase take out all the plugs and finger strainers which are located near the bottom of the case. Remove the two lifting eyes in the top of the case. These plugs and all passages are shown in the sectional views, Figs. 598 and 599.

Inspection and Repair.—After the engine has been completely disassembled and the parts laid out in groups on the inspection bench, they should be very carefully checked for defects. As a guide in this work a series of clearance charts is given at Figs. 608 to 612 inclusive. The maximum and minimum clearances allowed in manufacturing are shown on the chart, as well as the maximum clearance that is allowable in service before a part should be replaced. The latter figures are given more prominence by being underlined. These clearances should not be construed to mean that any part showing less wear is always satisfactory. The appearance of a part very often gives a better indication of its condition than does the actual dimension. The underlined figures are suggested as guides only where

looseness is the main consideration. When clearances are found in excess of those noted, an investigation should be started to determine the cause which is very often traceable to the wear or failure of some other part. New parts should be gone over very carefully and inspected for burrs or sharp corners. Burrs can be removed with a sharp scraper or a fine stone. This inspection is especially important in regard to oil holes in steel parts which are to run in babbitt, or bronze bearings.

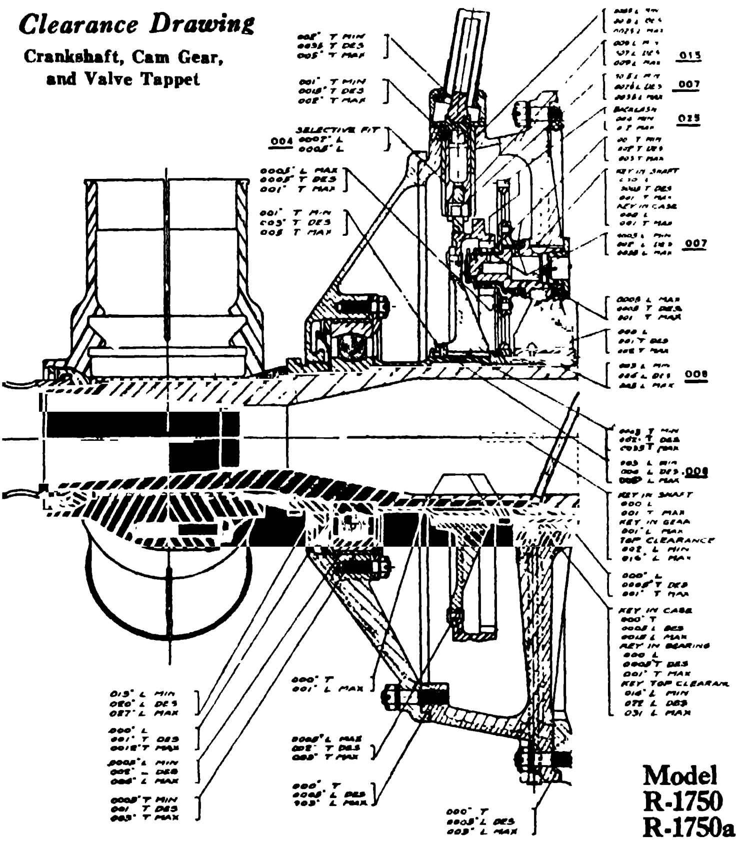


Fig. 609.—Clearance Drawing Showing Wright "Cyclone" Crankshaft, Camgear and Valve Tappet.

Pistons.—The pistons should be examined for scores, cracks, erosion and flatness of head. If cracks or severe erosion are found, or if the head is concave by more than 1/32 inch, the piston should be replaced. Light scores and rough spots can be smoothed over with a fine stone and kerosene. The clearances are shown at Fig. 608. In replacing a piston ream the wrist-pin bosses with a 1½ inch expansion reamer until the pin has .0015 inch

clearance. During the first run the bosses will close in on the pin leaving it a hand push fit when cold.

Piston Rings.—To check the piston rings for end clearance, set a piston in a cylinder with the bottom end ½ inch from the end of the sleeve. Then set the ring to be checked inside the sleeve and up against the piston. Such a position insures its being square with the cylinder bore. With a set of thickness gauges, check the clearance between the ends. If this clearance exceeds .050 inch, replace the ring. The piston-ring side clearance should be checked with the rings in position in the piston. The correct and maximum allowable clearances are given on the clearance charts at Fig. 608. Examine the rings for burred edges and, if necessary, run around the edges of each ring with a fine stone or file.

Scraper rings are liable to wear in more rapidly than compression rings due to the higher bearing pressure exerted. If the contact surface is more than half the width of the face, the ring should be replaced. The sticking of rings in the grooves is caused by the formation of excessive carbon and all ring grooves, therefore, should be cleaned out. When removing the rings be sure to keep them in the proper order so that they can be returned to the same grooves from which they were taken. This practice avoids unnecessary labor in refitting the rings in the grooves. The rings should be replaced with the side having the better bearing toward the bottom. Rings with blowbyes or burns can usually be lapped into a good bearing surface. This depends largely upon the condition of the ring and the decision as to whether or not the ring can be reclaimed rests entirely with the inspector or mechanic. When lapping in rings use an old piston.

New rings should be carefully fitted for both side and end clearance in accordance with the clearances given on the drawings. The side clearance is measured with a thickness gauge when the ring is in place. Be sure that the groove is free from carbon. The clearance can be varied by reducing the thickness of the ring in a grinding machine. If a grinder is not available, a lapping plate or a sheet of fine emery cloth supported on a smooth, flat surface can be used. Always check the ring with a micrometer to make sure the thickness is the same all the way around. The end clearance of the new ring should be checked as described in a previous paragraph and the clearance varied by filing the ends of the ring.

Piston Pins.—Piston pins should be inspected for cracks, wear and scoring. Cracked parts should be scrapped but, if the scoring or wear is not too serious, the pin can be smoothed with a fine stone. If a pin is replaced the piston bosses should be reamed out as described in the foregoing paragraph concerning pistons. If the old pins are too tight in the piston the bosses should be reamed out until the pins are a hand push fit when cold.

Cylinders.—Inspect the cylinder bores for smoothness and, if necessary, touch up any scores or rough spots with a fine, round stone. Check the bores for roundness with special dial indicator fitting. When inspecting the valve seats it should be remembered that carbon particles on the seats are very often mistaken for pits in the metal. A small scraper of convenient shape is very handy for determining whether or not a pit is genuine. Variation in the color of the valve seats is an indication of the degree of valve tightness but does not show which is at fault, the seat or the valve. The

trueness of the seat can be checked by inserting the valve seat cutter WA-333 in place and turning it through a complete revolution. The pressure on the cutter should be just enough to polish the seat without removing a perceptible amount of bronze. It may occasionally be necessary to recut a valve seat, using tool WA-333, due to irregularity or eccentricity of the surface. This should be done carefully to remove the least amount of metal possible

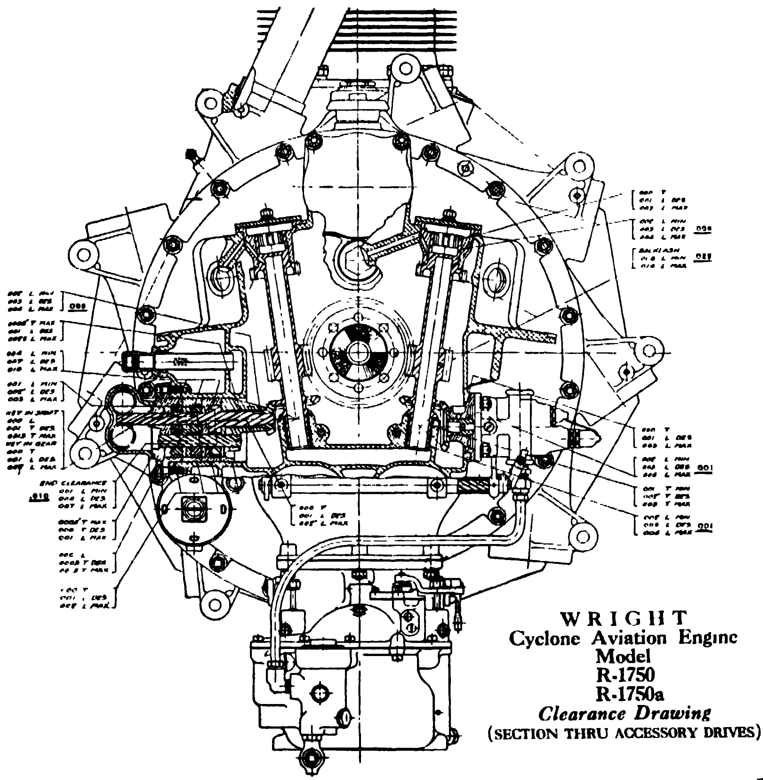
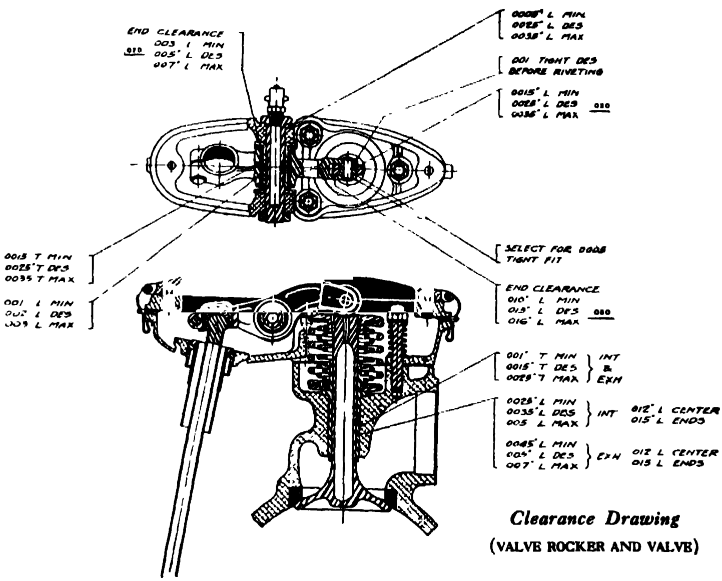


Fig. 610.—Clearance Drawing Showing Section Through Wright "Cyclone" Engine Accessory Drives.

The valve construction and clearances are shown at Fig. 611. Valves can be refaced, when absolutely necessary, in a standard valve facing machine. The valve-seat face should never be wider than the valve face. If this condition occurs, the width of the valve-seat can be reduced by using a 30 degree cutter in the standard valve-seat cutting tool and removing that portion of the seat which extends beyond the outer edge of the valve. The width of the seat should be about $\frac{1}{32}$ inch less than the width of the valve face. The valves may next be lapped in, using Clover "A" compound or its equivalent. The valves should then be tested with gasoline for tightness and the cylinders very carefully washed to remove

all traces of the grinding compound. It is very rarely that a valve seat works loose; but if this occurs, the cylinder should be returned to the factory for replacement of the part.

Valve Guides.—The valve guides should be tight in the cylinder heads and the bores should be smooth. If loose, they should be replaced with a larger part and if scored, should be lapped lightly until smooth. Check the clearance of each valve in its guide and replace any guide in which the valve has clearance over the maximum limit shown on chart, Fig. 611. The valve stems themselves very seldom wear, but if a stem is rough its diameter should be checked, and the valve replaced if the operator holds it advisable.



Clearance Drawing
(VALVE ROCKER AND VALVE)

Fig. 611.—**Clearance Drawing of Wright "Cyclone" Engine Valve Rocker and Valve.**

To remove a valve guide, heat the cylinder head by directing the flame of a blowtorch into the valve port and against the valve guide boss. Every few seconds the flame should be moved around over the outside of the port to avoid localized expansion and the danger of cracks. To determine the proper temperature for pulling the old guide or for inserting the new one the operator should be provided with a piece of soft solder. This should be rubbed against the guide at frequent intervals until it melts easily. The guide can then be pulled with tool WA-362 (intake) or WA-360 (exhaust). Allow the cylinder to cool down to room temperature and inspect the hole for smoothness and for size. If rough, ream very lightly and remove all burrs.

Check the diameter of the new guide and make sure that the correct amount of shrink will be obtained. The intake guide should be from .0008 to .0020 inch larger than the hole and the exhaust guide from .0008 to .0023 inch

larger. Make sure both the hole and the guide are clean and then heat up the cylinder as before. Coat the guide lightly with castor oil and tap it into position using mandrel WA-345 (intake) or WA-346 (exhaust). Hold the guide in place with a hammer handle until the cylinder has cooled down enough to grip it lightly and then strike it sharply with a fiber drift and a hammer to set it up snugly in place. The guides are too hard to ream and are ground to size in the factory. The clearance on the valve stem should be checked against the chart Fig. 611 and the guide should be lapped out if necessary.

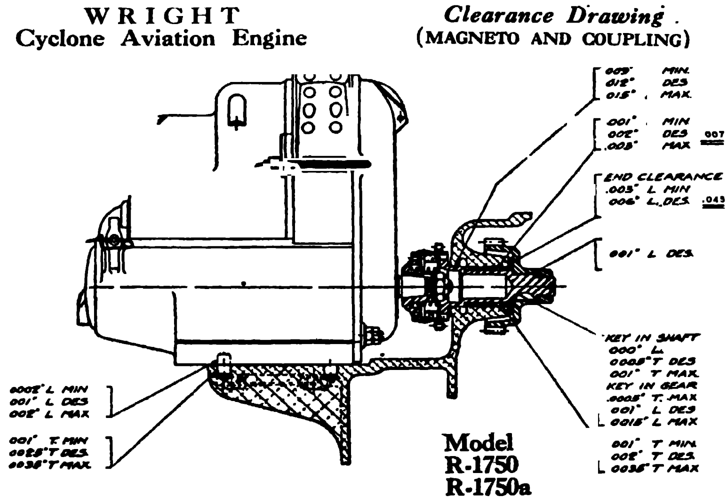


Fig. 612.—Clearance Drawing of "Cyclone" Engine Magneto and Coupling.

Sparkplug Inserts.—The threads in the sparkplug bushings should be clean and of the proper size, while the bushing itself should be tight in the cylinder. If the bushing is loose, drill out the two pins holding it in place and determine whether or not it can be used again. If the bushing threads are not excessively loose in the cylinder head, tighten up on the bushing, drill two new holes and drive in the new pins. If there is too much play, replace the bushing with a new part which is a snug fit and replace the pins as explained in the preceding paragraph. In drilling out the old pins and in drilling holes for the new pins, be very careful not to go any deeper than is absolutely necessary. The pins are 1/8 inch in diameter and 5/16 inch long. Check the rocker-box studs for cracks or twisting and see that the intake and exhaust port flanges are tight.

Valves.—If the valve seats are pitted or the heads are warped, considerable time can be saved in lapping by taking a light cut off the faces on a grinding machine. Valve stems are of uniform hardness so that it is permissible to remove signs of wear on the upper ends with a stone or in a

grinder. The stems should be inspected for wear and scores but should not be stoned unless it is considered absolutely necessary. The stem acquires a hard, glazed surface after a few hours of running and, under normal circumstances, will keep this glaze indefinitely. Inspect the exhaust-valve plugs for signs of salt leakage. An exhaust valve which is cooling properly will have a black head and will be black almost all the way up the stem. If the salt has leaked out, the head will be red or brown and the stem will be black for only a third or half of its length. Such valves should be replaced or returned for refilling.

Valve Springs.—Inspect the valve springs for breakage. They have exhibited a tendency to break off at the ends for an inch or so where the wire has been ground thin. Such a condition, however, does not impair their efficiency in operation. Smooth off the broken ends with a stone to prevent wear on the retaining washers. Inspect the retaining washers for wear and cracks.

Rocker Arms.—Inspect the rocker arms for cracks and signs of interference with any of the adjacent parts. Check the clearance of the bushing on the steel rocker-pin sleeve against the clearance chart at Fig. 611. Excessive clearance in any part of the rocker mechanism tends to cause objectionable noise when the engine is idling. See that the thrust wearing and the thrust face of the rocker-arm bushing are smooth. Clean out all the oil holes with a bit of wire.

Cam Followers.—The cam followers (tappets) should be a close fit in the guides in order to prevent oil leakage. Make sure that the push-rod ball cups are tight in the ends of the followers, that the wire circlets are in place, and that the rollers and pins are in good condition. The followers are a selective fit in the guides and the two are furnished as an assembly for spare parts. The clearances are given in chart at Fig. 609. Inspect the push rods for straightness and be sure that the ball ends are round and are tight in the rods. Inspect the rocker boxes for wear, cracks and signs of interference with any of the moving parts. If interference is found, the box can be relieved.

Cam.—The cam bearing should be smooth and free from scores, nicks and loose babbitt. If the surface of the babbitt is rough it may be smoothed up with a burnishing tool, but if it is regarded as satisfactory, it should not be touched. If the babbitt is loose in only one or two small spots, the loose pieces may be removed and the edges smoothed. It is preferable, however, to replace the bearing. Replacement is accomplished by drilling out the retaining pins and pressing out the old bearing in an ordinary arbor press. Check the cam hub for smoothness and press in the new part. The clearance figures are given at Fig. 609. If the cam lobes are rough, they should be smoothed with a fine stone. Inspect the gear teeth for wear.

Cam Drive Gears.—Examine the gear teeth for smoothness and wear. Make sure the gears are free of flaws and that the rivets are in good condition. Check the clearance of the bushings on the pin and if this is excessive when compared to the maximum allowable clearance shown on the clearance chart at Fig. 609 ascertain whether the wear has occurred on the pin or in the bushing. Make whichever replacement is necessary.

Crankcase.—All sections of the crankcase should be inspected for cracks, chafing at the parting flanges, and interference with moving parts. All studs should be tight. In replacing a loose stud, select an oversize part and turn into place, using white lead on the threads, to a height corresponding to that of similar studs. Inspect all bushings, first drill out the pins, if any, and heat the crankcase slightly with a blowtorch. The bushing can then be tapped out.

Gears.—All gears should be inspected for wear on the teeth, as well as for cracks, nicks and roughness. If the fault is not serious the teeth may be relieved with a fine stone.

Connecting Rods.—Examine the connecting rods for cracks, straightness or burning. The bushings should be tight and smooth and should have the proper clearances on the knuckle and wristpins. To replace either bushing, proceed as follows: Drill out the brass pin and push out the bushing in an arbor press. Clean up the hole in the rod and remove any burrs from the new bushing. Press the bushing into place in the rod after coating it lightly with castor oil or white lead. In replacing the wristpin bushing, take care to see that the oil hole in the bushing indexes with the hole in the rod.

The hole for the pin should be started with a pointed drill and finished with a flat-end drill to a point halfway through the bushing. The pin, of soft brass ⅛ inch in diameter, can then be inserted in place and riveted until tight in the rod. Insert a mandrel in the bushing during this operation. The bushing can then be reamed to size and the pin head smoothed over.

Master Rod.—The master rod should be inspected in the same manner as the articulated rods. In addition, the knuckle-pin holes should be checked for smoothness and the knuckle-pin oil holes in the rod should be examined for signs of plugging. The bearing should present a smooth clear surface.

Knuckle Pins.—The knuckle pins should be round, smooth and free from cracks and should be a tap fit in the master rod. Make sure the oil passages are clear and that the aluminum plugs are tight. In replacing a plug, proceed exactly as in replacing a connecting rod bushing. Always check the oil passage after re-assembling. The knuckle-pin lockplates are supplied a few thousandths oversize. If a plate is to be replaced, therefore, the new part must be fitted by filing the edges until it is a snug fit. Mark the new plate just as the old one is marked.

Supercharger Impeller.—Due to the high speed at which it operates, the supercharger impeller should be given special attention. Inspect it carefully for cracks, nicks, chafing and looseness. A cracked impeller should be scrapped but minor faults may be corrected with a fine stone. If the impeller is damaged it should be returned to the factory for repair and rebalancing. The shaft and bearings should be carefully checked for flaws, tightness and smoothness of rotation. The ball bearings on the high-speed shaft should have no perceptible shake.

Intake Pipes.—Inspect the intake pipes for dents and swaging in where the packing presses on the lower end, and for cracks where the upper end is flanged out. The dents and swaging can be removed by use of a hammer and a proper arbor on which to hold the part. Cracks, if not too extensive,

can be welded up. Make sure the flanges are not bowed, and if necessary straighten them on a flat plate.

Crankshaft.—The crankshaft, by reason of its importance to the engine, should be given special attention. Examine both sections for cracks and chafing. Check all the threads and splines, and, if necessary, smooth with a fine file. See that the oil pipe is tight, that the flaring is intact, and that the pipe is clean inside. Inspect the clamping surfaces for chafing and the clamp screw and washer for cracks. All bearing surfaces should be smooth and free from burrs. Ordinary roughness can be removed with a strip of fine emery cloth, and the journal can then be polished with crocus cloth. The crankshaft is built up as an assembly and the parts are not interchangeable. If either section must be replaced, both sections should be returned to the factory. If the entire shaft is replaced the clearances of the associated parts on the shaft should be checked against the clearances on the charts given at Figs. 608 and 609.

Supercharger Oil Seal.—The supercharger oil seal should be inspected for flaws, nicks in the sealing surfaces and loose rivets. The weather should be soft and smooth and generally capable of maintaining a tight joint. The fiber bushing should be free from cracks and should have the proper clearance on its journal. To replace the leather in the front oil seal 21,178, proceed as follows: With a sharp cold chisel chip the heads off the front ends of the eight rivets holding the oil seal assembly. Then take a small punch and drive the rivets through the seal toward the rear. This should be done slowly and carefully to avoid distorting the rear ring 20,914. The rivets will probably stick in this ring and should next be chipped off and ground down until they are almost flush with the ring. They can then be tapped out of the ring. Inspect all the parts for burrs or bending and put in good condition.

Thrust the new rivets through the holes in the ring 20,914 and in the new leather. Put the leather on with the smooth side facing the rear. Then assemble in place on the rear face of the oil seal plate and invert the assembly onto a block of wood which will fit the central depression of the oil-seal plate and will bear against the rivet heads. Compress spring 21,176 until it bottoms and secure it with two loops of small copper wire. These loops should be on opposite sides of the coil and should have the twisted ends on the inside to facilitate removal.

Place the steel ring 21,179 in position on the leather and insert the compressed spring in the steel cup. Slip the cup over the rivets and proceed with the riveting. Hold one rivet punch in a vise to support the rear end of the rivet and head over the front end with a small hammer and another rivet punch. When the first has been headed over, start the rivet on the opposite side. Always select a pair of rivets, one on either side. As soon as the riveting has been completed, remove the wires on the spring and allow it to assume its normal position. Be sure that the thrust washer 21,179 is in its correct position.

Accessories.—In other chapters of this book will be found instructions covering the inspection and maintenance of the magnetos, propeller hub and starter. The carburetor will be described at the end of this chapter. Clearance charts for the accessory drive parts are given at Figs 610 and 612.

Assembly.—The successful operation of the engine is absolutely dependent upon the attention given to every detail in inspection and assembling. It should be constantly borne in mind that the slightest neglect on the part of the inspector or mechanic may result in the failure of the engine and the possible loss of one or more lives.

Precautions in Assembling.—Cotter pins and lockrings which have been badly bent should never be used again. Great care should be taken to prevent dirt, dust, cotter pins, lockwires, nuts, washers, and other small parts from falling into the inside of the engine. These might work into the gears or oil lines and cause serious damage. The various precautions previously given in connection with assembly of "Whirlwind" engines in the preceding chapter apply to this engines as well. All parts of the cylinder, piston and connecting-rod assemblies are numbered, excepting the push rods, valve springs, and valve-spring washers. In disassembling, it will be noted that many other parts are numbered or marked to identify their locations in the engine. These marks should be also noted as the engine is assembled.

Crankcase.—Clean the crankcase thoroughly using compressed air or a clean rag to remove dust and dirt which may have accumulated since the disassembly. Replace oil plugs and finger strainers. Safety wire where required. Mount the case on the assembly stand.

Crankshaft and Master Rod.—Clean the crankshaft and replace the crankshaft front bearing sleeve. This will be a light tap fit into place. Put the front section of the crankshaft in a vise, holding it by one side of the counterweight with the crankpin facing the mechanics. Lubricate the crankpin and master rod bearing thoroughly and slip the master rod into place on the pin. Be sure that the knuckle-pin lock-plate screw holes are facing the front of the shaft.

Replace the rear crankshaft bearing if this part has been removed. Drive spreader WA-316 into the split end, oil the end of the crankpin and mount the rear section of the crankshaft in place. Knock the spreader out and put in the washer and crankcheek capscrew. Using a lead or rawhide mallet, adjust the position of the rear cheek until the master rod bearing has .018 to .020 inch end clearance and the two counterweights are in line as indicated by the free fit of the crankshaft aligning bar WA-357 in the two holes in the counterweights.

Check the length of the crankcheek capscrew with a pair of three- to four-inch micrometers and then tighten up, using wrench WA-340, until the length of the screw has been increased .0035 inch by the tension. While the screw is being tightened the aligning bar should be withdrawn from the front counterweight to avoid straining if the shaft is twisted during this operation. As soon as the screw is tight, the alignment should be checked again. If the bar is still a free fit in both holes, the screw may be cottered. Oil the rear bearing and the bronze ring in the crankcase and place the shaft in position in the case. When this is done, it is necessary for the master rod to be in line with and between the counterweights. The shaft is inserted at an angle until the end of the master rod has been thrust out of the No. 7 cylinder opening and then straightened out and dropped into place.

Articulated Rods.—Clean the articulated rods and knuckle pins and lubricate the pins and bushings. The knuckle pins and master rod are so designed that the rear ends of the pins are a tap fit in the rear flange and the front ends, which have a shoulder .010 inch larger in diameter, are a tap fit in the front flange. Four small lockplates each match up with the shouldered sides of two of the knuckle pins and prevent them from rotating. Insert the two articulated rods and knuckle pins which employ the same lockplate. The rods are numbered in the bottom of the channel near the knuckle pin end and the pins are numbered on the front face. These should index with corresponding numbers on the front of the master rod.

The pins should be lined up by tapping until the lockplate fits in place (lockplates are also numbered); and then they should be tapped into place a little bit at a time until both are home. Use drift WA-315. The lockplate screws should then be put in and the safety wires replaced. It is of the utmost importance that the pins be inserted in their proper places according to their numbers and that they be correctly lined up and securely locked. Failure of any pair of holes to register will result in cutting off the supply of oil to the knuckle pin bearing.

Intermediate Section.—Replace the camdrive pinion pin in the rear wall of the intermediate section not forgetting the key. The pin should be tapped in until the shoulder is hard against the aluminum and the locknut, 20,361, should be put on the rear end. This nut should be tightened with tool WA-327, until the cotter-pin holes line up and the cotter pin can be inserted. Oil the pin and bearing and assemble the camdrive gear and pinion in place. Tighten the nut on the front end of the pin and cotter.

Assemble the tappets (cam followers) in place in the case, noting the numbers of the parts. As the tappets are a selective fit in the guides, this must be done carefully. Oil all parts before assembling, and do not forget the lockring at the outer end of each tappet. Oil the crankshaft front bearing, place the intermediate section in position on the front of the main crankcase and tap home. Make sure that the oil-return holes inside at the bottom are lined up with those in the main case. Tighten and safety wire at hold-down nuts.

Timing.—The timing of the Cyclone engine is fixed and all the gears are marked to give the correct values without adjustment. Consequently, great care should be taken in assembling.

Slip the camdrive gear on the crankshaft and tap home so that the two zeros come one on either side of the one zero on the idler camdrive gear which is mounted on the crankcase wall. Oil the cam hub and the cam-bearing sleeve and slip the sleeve inside the hub. Slide them down the shaft and mesh the internal gear on the cam with the drive pinion as shown at Fig. 613 so that the line and the zero on the cam are lined up with the line on the No. 1 cylinder exhaust-valve tappet. The sleeve should then be tapped home. The timing is then set but should be checked as soon as the No. 7 cylinder has been assembled on the engine. For this reason the assembling of the front cover should be left until later.

Cylinders.—If the valves have been ground, the greatest care should be taken to clean the grinding compound off the valves, ports, and valve seats. Put both valves in place and invert the cylinder over the assembly block.

Snap the wire circlets into place in the grooves near the top ends of the valves. Set the rocker boxes in place and put the nuts and washers on the two front studs. These nuts should be turned down until tight so that the slot and hole in the stud are lined up for the cotter pin. Do not use excessive force in tightening the nuts, as such treatment may result in twisting the studs. If alignment cannot be obtained with normal effort, another nut should be tried. The studs are flat to permit bending and, consequently, do not resist twisting as well as a round stud. After the rocker box and the nuts are in place and cottered the studs can be checked for twisting by observing the direction of the cotter pin holes.

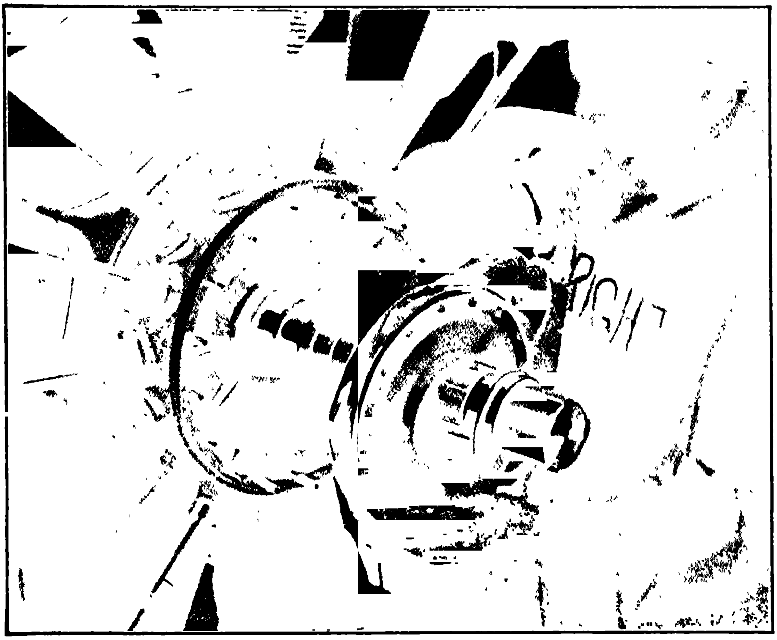


Fig. 613.—Assembling Cam Ring on Wright "Cyclone" Engine.

Assemble the washer, spring, and nut on the rear stud and turn down on the nut just far enough to permit the insertion of the cotter pin. Slip the lower retaining washer, the three valve springs and the upper retaining washer into place on the valve. Thrust a smooth piece of bar stock through the rocker-pin hole and hook the end of the valve-spring compressor WA-300 underneath. Compress the valve springs and slip the split locks into place. Attach the push rod housings by screwing up on the clamp nut at the upper end. This nut should not be tightened as it has to be adjusted later.

Clean the pistons thoroughly and make a last-minute inspection of the rings to make sure they are correctly assembled. Starting with the No. 7 or master-rod cylinder, assemble the piston and pin in place, using piston

pin drift WA-339. The crankshaft should be in the top center position for that cylinder and the piston should be put on with the cylinder number, which is stamped on the head, over one wristpin boss towards the front of the engine.

Turn the piston rings so that the gaps in any pair of rings are not in line and coat the piston and cylinder bore thoroughly with engine oil. Cover the cylinder flange with a light coating of soft soap to prevent oil leakage. Use clamp WA-331 to hold the rings and slip the cylinder over the piston as shown at Fig. 614. Just before the bottom of the cylinder sleeve passes over the wristpin make sure the wristpin end plugs are both in place. Tighten the cylinder hold-down nuts. Tighten the push-rod housing clamps down to the case. In doing this, care should be taken not to break the studs.

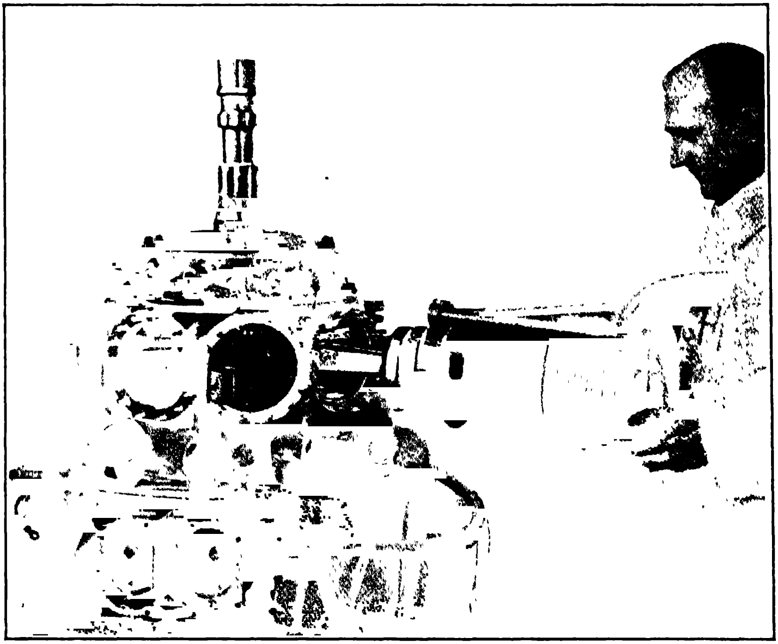


Fig. 614.—Assembling No. 7 Cylinder on Wright "Cyclone" Engine.

Wipe off the rocker-arm pin assembly and assemble in place. The Alemite lubricators point towards the inside of the cylinders. Tighten the rocker-pin nut and cotter. Dip the push-rod balls in engine oil and insert the push rods in the housings. Inspect the push-rod adjusting screws and make sure the ball cups and circlets are in place. Insert the adjusting screws in place. After No. 7 cylinder is in place the other cylinders should be assembled in rotation and in a similar manner.

Rocker Box and Valve-Tappet Clearances.—In setting the tappet and rocker-box clearances be sure that the piston of the cylinder in question is

at top center on the firing stroke. Unless this is done, it is quite possible for one of the tappets to be riding unnoticed on the rising part of a cam, causing an error in the tappet setting. To avoid the possibility of making this error proceed as follows: Turn the crankshaft until the valves of the No. 1 cylinder indicate that the piston is on top center at the beginning of the suction stroke. At this point both the valves will be open and the large spline in the shaft will be facing No. 1 cylinder. If the propeller is mounted on the shaft, one of the blades will be in line of this spline. Then turn the shaft through one complete revolution and set the clearances on the No. 1 cylinder in the manner prescribed in the next paragraphs. Having done this, turn the crankshaft in the direction of rotation until the spline or propeller blade is facing No. 3 cylinder and set the clearances. Taking each in the firing order (1, 3, 5, 7, 9, 2, 4, 6, 8), repeat on the rest of the cylinders.

To set the rocker-box clearance proceed as follows: Slack off on the push-rod-housing adjusting nut with tool WA-256 until the push-rod housing is free. With a set of thickness gauges check the clearance under the rear end of the rocker box and tighten the adjusting nut until a clearance of .031 inch to .035 inch is obtained. Then tighten the clamping screw. It is essential that this adjustment be made when both valves are closed in order to prevent errors caused by the forces set up when the valves are opening and closing. Check the tightness of the push-rod housing by attempting to shake it at the upper end. If there is any perceptible shake increase the clearance under the rear of the rocker box until the housing is just tight. It is usually possible to twist the housing even when the proper adjustment has been made, so this condition should be disregarded.

After setting the rocker-box clearances, proceed as follows to set the valve-tappet clearances: First the push-rod end of each rocker arm should be tapped sharply with a hammer handle to make sure the roller is riding on the cam. The cam followers are fitted with very little clearance and are sometimes too tight to be moved easily with the fingers, thus necessitating this operation. Loosen the clamping screw on the push-rod end of the rocker arm and with a large screwdriver, turn down on the adjusting screw until the rocker roller touches the valve plug. This point is best determined by rocking the roller back and forth with the thumb and forefinger and noting the point at which contact is made. Then back off the adjusting screw until the arrow on top has passed ten divisions of the scale on the rocker arm. Each division is equivalent to a .005 inch clearance on the valve stem. Lock in place by tightening the clamping screw. Replace all the rocker box covers except those on the No. 1 cylinder.

Checking the Timing.—For checking the timing, a timing disc is necessary and can be constructed as follows, if part WA-336 is not available: First cut out a disc of sheet aluminum ten inches in diameter and in the center cut a hole 2⅞ inches in diameter. The disc can then be slipped over the threads on the end of the shaft and up against the ends of the splines. Tap on the front side of the disc with a hammer until the end of each spline has been imprinted on the soft metal. Cut out these portions with a pair of shears, leaving a set of teeth which will fit in the splines on the shaft. With the disc in position at the rear end of the splines, cut and fit a pointer whose tip is near the outer circumference of the disc and whose base is

held down by nuts on the studs in the front of the intermediate section.

Insert the top center indicator WA-293 in the front sparkplug bushing and determine the top center position of the No. 1 piston. Make a mark on the disc at the point indicated by the pointer. Turn the crankshaft and observe the point of opening of the No. 1 intake valve. As in checking the clearance, strike the push-rod end of the rocker arm with a hammer handle to make sure it is down and note the point of opening by rocking the roller with the thumb and forefinger. Mark the point observed on the disc. Turn the crankshaft past top center and, in the same manner, note the point of closing of the No. 1 exhaust valve. Mark this point on the disc also. On this timing disc, 25 degrees is equivalent to $2\frac{11}{64}$ inches measured along the circumference of the disc. If a mistake has been made in assembling the gears, the timing will be at least 40 degrees from these values. Replace the rocker box covers on the No. 1 cylinder.

Front Section.—If the front section has been taken down, it should be re-assembled and the bearing well oiled. Oil the crankshaft and assemble this section on the engine, tapping down until home. Replace the hold-down nuts and washers. Oil all threads and put on the thrust-bearing nut. Tighten up, using spanner wrench WA-328 until the shaft has been pulled up into place and the nut is home solid.

Intake Pipes.—Replace the rubber packing rings and the packing nuts in the crankcase and insert the intake pipes in place. Slip the gaskets at the cylinder-head end into place and replace the three capscrews. Then, using tool WA-299, screw down the packing nut.

Inverting the Engine.—The engine must now be inverted for assembling the supercharger and rear sections. If a rotating stand is being used, this is quite simple; but, if not, it is more complicated. First lift the engine using hoisting eye WA-337 on the end of the crankshaft and a chain hoist. Then pick up the rear of the engine using another chain hoist, a wire rope sling and two hoisting eyes WA-236, screwed into the breather holes in the rear of the crankcase main section. A wooden spreader should be used to keep the two sides of the sling away from the No. 1 cylinder.

Some sort of a stand for holding the engine with the crankshaft down should then be available. The simplest form is a cross made from two pieces of eight by eight inch pine about four feet long and with a hole through the center just large enough to receive the front end of the crankshaft. This stand can be mounted on castors for convenience in moving. Lower the front of the engine until the weight rests entirely on the rear end hoist. Remove the front hoisting eye and lower on the rear hoist, guiding the shaft into the hole in the stand.

Supercharger Oil Seat and Diffuser Wall.—Examine the contact surfaces carefully for nicks. Shellac the surfaces and assemble the oil seal on the engine. The contex bushing 20,920 should first be inserted in place and the lockwire snapped on the forward end of the bushing. The oil seal is held in place by six flat-head screws which should be carefully locked in place with a center punch. Make the punch mark in the aluminum near one end of each screw slot so that the aluminum is forced into the slot. This is very important for if one of the screws starts to back out, considerable damage is apt to result.

Supercharger Section.—Assemble slinger 20,570, bearing 20,429 and nut 20,484 on impeller shaft 20,445 with wrench WA-309, and secure them with a cotter pin. Put on washer 20,460 and thrust this assembly into the impeller-shaft ball-bearing cage and assemble the cage in the supercharger section. Its position is determined by key 17,008. Put on nut 20,459 with tool WA-356 and secure it with a cotter pin. Place slinger 20,718 in position at the front of the housing and tap the front bearing 20,428 into place. Put in the nut 20,466 and tighten up with wrench WA-326 until the cotter-pin holes line up. Slip the rear slinger 20,461 into place and then cotter the nut. The impeller-shaft assembly can then be slipped into place and tapped home.

The impeller is a selective fit on the splined shaft and should be replaced in its original position as indicated by the marks on the ends of the splines. Tighten impeller retainer nut 20,684 with tool WA-318 and lock with setscrews 20,920. The setscrews should be carefully locked in place with a center punch in the manner previously described. Slip the two spacers 21,228 over the studs and assemble the supercharger section assembly on the engine, first making sure that the contact surfaces are clean and free from burrs. The supercharger section is held in place by nuts and washers on the two studs. These nuts should be turned up securely with socket wrench WA-313 and cottered.

Supercharger Drive.—Tap the crankshaft-extension bearing 20,427 into the steel cage 20,475 and assemble the cage with the aluminum supporting casting 21,149. Tighten the six fillister-head screws and safety wire the three pairs together. Thrust the crankshaft extension 20,495 through the bearing and tap home. Tighten nut 20,565 with tool WA-311 and cotter. The whole assembly is then assembled onto the rear wall of the supercharger section, where it is held in place by six nuts. These should be safety wired. The supercharger and generator shaft 20,523 is splined to receive the three gears 20,444, 21,254 and 20,496 which are the impeller-drive, intermediate and generator-drive gears, respectively. The front bearing 6,207 should be tapped onto the hub of the impeller gear before it is assembled on the shaft. The two front gears are held in place by nut 20,485 which should be screwed up until tight and then be cottered. The shaft should then be set in place with the bearing resting in the cast-aluminum drive support and the bearing cap 20,449 tapped into place. Tighten the two retaining nuts and cotter.

Rear Section.—The rear section should next be completely assembled. Be sure that all bushings and bearing surfaces are clean and well oiled. First thrust magneto driveshafts 20,532 into place and insert the keys 11,680. Push the drive gears 21,695 onto the shafts and secure them with nuts 15,882. Hold the outside gears and turn up on the nuts until they are snug and can be securely cottered. Then drop the two vertical driveshafts into place. These are identical except for the lower bevel gears of which the oil-pump drive gear is the larger. Slip the upper housing 20,999 into place, and, if they are being used, the gun synchronizers. A gasket 21,090 is used between the housing and the cover or synchronizer. Before attaching the oil pump slip the gasket 21,383 over the studs. The pump cannot

be put on in any but the correct position on account of the locating dowel. The fuel-pump drive gear 20,498 should next be inserted in the housing 20,556 and assembled on the engine. Gasket 18,294 is then slipped over the studs and the fuel pump is secured in place.

The oil strainer rests in its housing with the open end facing the rear of the engine and is held down by a coiled spring. The strainer cap is provided with a copper-asbestos gasket. The finger strainers should also be replaced. The installation of the strainer screen is clearly shown at Fig. 599. Insert the main oil-pressure valve and spring inside the adjusting screw and screw in until it is approximately at its previous position. Replace the gasket, locknut and cap. Replace the idle oil-pressure adjusting-screw locknut and cap. Slide the generator-drive gear 20,496 into place on the supercharger and generator driveshaft.

Inspect the contact surfaces for nicks and assemble the rear section on the crankcase. The contact surfaces of the induction-passage joint should be lightly coated with clean shellac The generator drive has been left off to enable the mechanics to guide the impeller and generator shaft into the bearing in the rear section. Secure the rear section with nuts around the outside and with the five capscrews which insure the tightness of the joint in the induction passage. These screws are of three different lengths but can be easily assigned to their proper positions. Safety wire all screws.

The magnetos and carburetors have been left off up to this time in order to avoid unnecessary weight when handling the rear section and may now be assembled on the engine. In mounting the magnetos, remember that the control levers point to the rear of the engine. If the two are interchanged (incorrectly mounted), the levers will point to the front of the engine. Make sure that the felt and the springs are in place in each magneto coupling and apply a small quantity of oil to the felts. Slip the coupling over the gear on the magneto, press it back as far as it will go and turn slightly so that it locks in place and is out of the way. The magneto coupling is shown at Fig. 612. Wipe off the bottom of the magneto and the face of the mounting pad and mount the magnetos in place. The coupling will partially engage during this operation. Rock the magneto back and forth until it slides down over the dowel and secure it with the four capscrews in the base. These screws should be lockwired together. Never strike a magneto with anything wooden or metallic as this has a tendency to weaken the magnetic strength of the armature. Assemble the control mechanism and check the magnetos to make sure each breaker is in the full advanced position.

Clean the contact surfaces and the gaskets carefully and assemble the carburetor on the engine. Check the throttle motion and see that the economizer needles do not hit the studs. Insert the generator drive in place, and if desired, assemble the generator on the engine at the same time. The drive flange is located by a dowel in the rear section. Gasket No. 20,104 is located between the drive assembly flange and the cover or generator. Safety wire the four nuts.

Magneto Timing.—Raise the engine clear of the stand, using a chain hoist and the two rear hoisting eyes. Slip the timing disc on the crankshaft and then raise the front of the engine by means of a hoisting eye (WA-337)

on the forward end of the shaft until the shaft is horizontal. Assemble the pointer loosely on the front section studs and insert the top center indicator in the front sparkplug hole of the No. 1 cyilnder, WA-293, and secure the pointer so that it indexes with the zero on the top center mark on the disc. Set the No. 1 piston at 30 degrees b.t.c. on the firing stroke. At this point both valves will be closed. (Both will have clearance.) Rotate each magneto until the marks on the distributor gear and the magneto front cover index and indicate that the No. 1 cylinder is firing. There are two marks on one side of the magneto and one on the other. Insert a piece of thin, oiled paper (such as that commonly used on cigarette packages) between the breaker points of one magneto and rotate slowly until the points separate and release the paper.

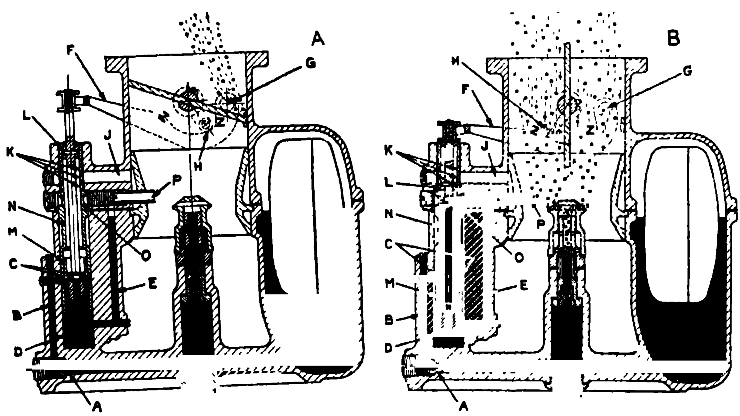


Fig. 615.—Views Showing Action of Type NA-Y7A Stromberg Carburetor at Closed Throttle at A and Wide-Open Throttle at B.

Insert the point of a screwdriver between the gear and the front cover to prevent motion of the gear and rotate the coupling until the two sets of gears mesh and the coupling slips into place. Repeat with the other magneto. Replace the papers between the breaker points and check the settings by rotating the crankshaft and noting the points at which the breakers open. The two magnetos should be synchronized within ½ degree and should be within one degree, plus or minus of 30 degrees b.t.c. If the setting is correct snap the lock rings 619 in place on the couplings, clean all traces of paper from the breaker points and replace the distributor blocks and breaker mechanism covers.

Installation and Test.—The engine is then ready for installation in the airplane. It should be inspected as if it were a new engine in accordance with the instructions previously given. The run-in should be made in accordance with the following instructions: After the engine has been installed in the plane, it should be run-in for a period of not less than two hours. Additional run-in time depends on the number and nature of the parts replaced and rests largely with the judgment of the operator. New

pistons, piston rings and cylinders require the most running-in time. A maximum of five hours total is recommended when several of these parts have been replaced. Starting at about 600 r.p.m., the speed should be gradually increased up to the last fifteen minutes, which should be run at about 90 per cent of the full throttle r.p.m. on the ground. The plane should be headed into the wind during this run in order to obtain the maximum cooling effect. If the performance of the engine is satisfactory during this test the plane may be considered ready for flight.

Instructions on the Stromberg Model NA-Y7A Carburetor.—The model NA-Y7A carburetor embodies the same basic principles throughout all Stromberg models and it is advisable that a thorough study be made of the chapter on Stromberg Aircraft Carburetors, before attempting to master the details of this particular one. It contains complete information on design, construction, operation, adjustment and servicing, and assimilation of this information will make easy a complete understanding of the carburetor. In one particular this carburetor has an addition to the standard construction as previously covered. This consists of an economizer whose primary function is to provide the proper lean mixture at cruising speeds with a quite rich mixture at full throttle. This mixture range allows of cool running with maximum power at full throttle, together with the best economy at partial throttle.

The specification in this carburetor has been evolved after a great deal of painstaking effort by all parties concerned in the production and operation of the engines and carburetors, and represents the combined result of much dynamometer, torque stand and flight work. The specification should never be changed unless absolutely necessary and then only when sufficient data are at hand to determine exactly the nature and extent of the change desired. The specification is usually given on an aluminum tag riveted to the carburetor.

The carburetor has two barrels of $2\frac{11}{16}$ inch actual internal diameter with a single throttle shaft running through the two barrels. Each barrel has a completely separate metering system, including the idle, though they both feed from the same float chamber. The float mechanism is of the Y type wherein there are two floats in two chambers. The floats, however, are rigidly connected together and the float chambers are joined through a fuel passage so that the resulting action is that of a single unit, and the net effect of the construction is to maintain a constant level on the discharge nozzles regardless of the angle the airplane assumes on the ground or in normal flight. The mixture control, idle operation and adjustment, etc., are all standard. The main metering jets are located in the bosses of the main discharge nozzles.

The economizer action mentioned above is actually a combination of devices in that aside from furnishing a rich mixture at full throttle, on a quick throttle opening an extra fuel supply is put into the barrel to aid acceleration. Figures 615 A and B illustrate the economizer action, A showing the position assumed when the engine is idling, and Fig. 615 B at full throttle. The position and action of the fuel itself is also shown by the black sections. The figures illustrating the economizer action do not show the

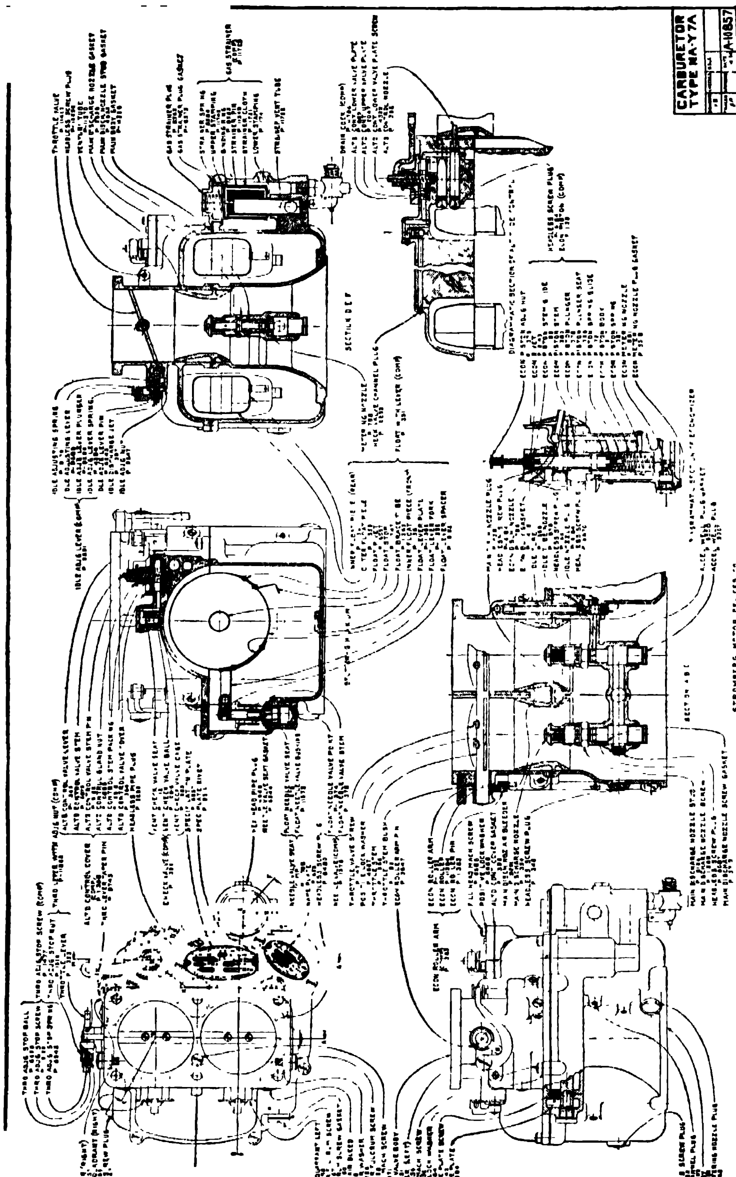


Fig. 616.—Sectional Drawings Showing Construction of Type NA-Y7A Stromberg Carburetor Used on Wright "Cyclone" Engine.

entirely correct detail of the actual construction, more particularly the location of the different parts. They are drawn to illustrate as simply as possible the basic action unhampered by the actual structural requirements. After the principle of operation is thoroughly understood, reference should be made to Fig. 616 which shows the construction on the carburetor as it is. It is well also to follow the details through on an actual carburetor so that each part and its function are known. The fuel enters the economizer from the float chamber through the Economizer Metering Jet A (Fig. 615 A), which is of the same construction as the standard Main Metering Jet used in all Stromberg carburetors, and serves to meter the fuel passing through the economizer. By changing the size of this jet, the amount of maximum economizer action is regulated. The fuel, after passing through this jet, flows up the passage B and across to the economizer proper. It enters the economizer through the port C, filling up the economizer well space in the float chamber as shown in the illustration.

The economizer proper consists of two pistons, L and M, working in a sleeve N. The upper piston L works to regulate the air bleed to the economizer while the lower piston M operates on the fuel flow. The air bleed at practically atmospheric pressure enters the passage J from behind the venturi, and through the ports K, K, K, etc., passes to the interior of the economizer. Through the common fuel and air passage O, it goes to the discharge nozzle P. This air bleed actually serves to relieve the suction existing at partial throttle openings so that fuel will not be drawn past the piston M (clearance must be allowed for the operation of the piston) or through the passage E. As the throttle is opened, the economizer moves downward, being actuated by the cam lever F which is pivoted at G and operated by the lever and roller H directly connected to the throttle valve stem. At intermediate throttle positions, the piston M has moved downward until it covers the port C as shown in Fig. 2. It will be noted that the piston L has not moved downward enough to close off the air flow to the economizer.

As the throttle is opened, the economizer is moved farther downward until at wide open throttle the position shown in Fig. 615 B is reached. The fuel flows through the port C, straight up the economizer and out the discharge nozzle. The piston L now covers the air ports K, K, etc., so that the suction on the economizer system is at a maximum. The clearance between the piston L and its guide is great enough so that the suction on the economizer system is at a maximum. The clearance between the piston L and its guide is great enough so that there is a small air leakage past the piston. This air mixes with the fuel at O so that an emulsion of air and fuel issues from the nozzle P.

In the above description the action of the economizer has been considered only at fixed throttle positions. The actual movement of the economizer is controlled by the shape of the cam portion Z-Z of the lever F. This shape is made to give a rapid motion of the economizer over the first part of the throttle opening, this movement gradually decreasing until over the last part of the opening the economizer had practically no movement. It is this rapid movement of the economizer which provides the added accelerating charge on quick throttle openings. As the piston M moves down-

ward the fuel supply in the space D is forced out and up the passage E, discharging through the nozzle P. This provides instantaneous operation regardless of the speed of throttle opening.

Starting.—For starting the engine the general practice given in the chapter on carburetors is recommended. It can readily be seen that with the low speeds used in cranking, it is much easier to start the idle system to functioning than the main well. In starting, therefore, the throttle should be kept closed, or nearly closed, at least until the engine fires.

This carburetor has but few moving parts to wear. It is of the plain tube type and the only moving parts are those of the economizer. These are designed for a minimum of wear and with ordinary care will last indefinitely. Once set for the engine the carburetor should function properly at all times, unless there is some actual part breakage, stoppage of fuel or similar failure. The throttle shaft is of brass and is held in monel bearings. The float pivot pins are of monel and work in bushings. There should be no evident wear after some hundreds of hours of service. The range of idle adjustment on this carburetor is in excess of that needed to care for any variation in engine requirements. It is effective only from extreme idle to approximately 600 or 700 r.p.m. of the engine. That is to say, it is intentionally so designed that any specific idle adjustment required for particular engine conditions will not affect the main running range.

There is a separate idle adjustment for each barrel and the actual regulation is made by swinging a small lever on a quadrant. Care should be taken in making this adjustment. Primarily it is, of course, necessary to furnish the engine with the proper mixture so that all cylinders are firing at all times smoothly and positively. The adjustment should be made when the engine is warm but the operation cold should be cared for by setting the mixture as rich as possible and still fulfill all engine requirements for good operation in a warm condition. The carburetors should at every opportunity be checked carefully to see that all parts, screws and connections are tight and that all controls are functioning properly. See that the packing gland on the altitude control valve stem is sufficiently tight to prevent air leakage at this point. The fuel strainer in the carburetor should be cleaned regularly.

Due to limitations of space, there is very little clearance between the top of the economizer stem and the carburetor attaching studs and nuts, when the economizers are in the raised position. See that there is no interference at these points when the throttle is completely closed. The economizers are carefully adjusted and locked in the proper position at the factory. They should not be disturbed unless it is known for certain that they are not functioning correctly. If it does become necessary to make an adjustment, it should be done carefully and with a full knowledge of the construction and operation of each part. Both the adjusting nut on the top of the stem and the lock nut on the bottom of the piston are secured in place by spreading the economizer stem at the ends. It will, therefore, be necessary to use some force in unscrewing these parts and when replaced they should be again locked in place.

Overhaul.—As noted under "Bench Inspection," in the Carburetor chapter the carburetors, at any time it is deemed necessary, may be partially disassembled and given a thorough inspection to determine their condition. It is recommended that this be done in all cases of doubt. The operation of the engine depends to such a large extent upon the carburetor that its condition should be kept at all times as nearly perfect as is possible. For an overhaul, the carburetor should be almost completely disassembled so that the condition of every part can be determined. An aircraft carburetor which is properly overhauled should be in exactly the same condition as a new one. This requires a thorough knowledge of the carburetor and painstaking attention to every detail of disassembly, examination and re-assembly. The procedure given in the chapter devoted to the Stromberg Aircraft Carburetor should be followed in all particulars. The illustration of the carburetor shown at Fig. 616 should be examined carefully, with particular reference to the actual mechanical construction so that the disassembly and re-assembly can be properly made. The carburetors have been designed in so far as possible to require no special tools. However, as is necessary for all good work, the best of tools should be used and only those which are exactly fitted to the work. Particular care should be taken to see that gasket surfaces are not injured. Especial carefulness is also required for the proper assembly and disassembly of the float mechanism. This is made of sturdy construction to stand hard service, but it is necessary for proper operation that it be assembled with the pivots accurately lined up, and the needle in its proper location at all positions of operation so that there is no tendency to bind. Be certain that the float does not rub on the carburetor walls.

To disassemble the Model NA-Y7A carburetor, it is necessary first to remove the nine fillister head screws which hold the two halves of the carburetor together. One of these screws is quite long, passing from the upper flange surface completely through the upper half. It is located immediately behind one of the center attaching stud holes. Sometimes these halves stick together after long service but will loosen easily with a few light blows from a rawhide mallet on the lower half, holding the upper half securely in one hand. After the halves are loosened from each other, care should be exercised in separating them. If they are not separated by drawing the surfaces directly apart, the economizer guides may be bent. To remove the venturi tubes, it is necessary to first remove the economizer discharge nozzles from both barrels and the altitude control suction nozzle from the right barrel. These nozzles screw into the upper half and are reached by removing the three small headless screw plugs on the outside surface of the casting. Then unscrew the two plugs in the bottom of the main discharge nozzle bosses. Unscrewing the accelerating well screw will allow the removal of the main discharge nozzle proper and the accelerating well screw. After these are out, the accelerating well stud should be unscrewed from the main discharge nozzle. The location of the gaskets removed should be carefully noted so that they can be put back correctly in place when the re-assembly is made. Remove the strainer from the strainer chamber.

The float assembly and float needle valve can be taken out by unscrewing the two float fulcrum screws and removing the gasoline baffle plate. The float fulcrum screws should be marked so that each will be returned to the side from which removed. The gasoline baffle plate should also be marked to insure freedom from any binding action due to reversement in assembly. Unless it is known that the float level in the carburetor is incorrect, it is not necessary to remove the float needle valve seat. This has been securely placed in the carburetor and is set at the proper position to maintain the correct fuel level. If an examination shows that a new needle is needed, it will then probably be necessary to remove the seat to obtain a tight fit with the new needle and to reset the level. Remove the idle air bleeders and the idle tubes by unscrewing from the upper half. See that drilled passages are open.

The mixture control valve is opened to inspection when the cover is removed by unscrewing the small fillister head screws. If the mixture control valve is removed, mark carefully as each valve is individually fitted and they are not interchangeable. If the throttle valves fit accurately and the throttle shaft works freely in its bearings, it is not necessary to remove these. In case of removal the throttle should be marked for refitting. These throttles are machined accurately at the exact angle they lie in the carburetor barrel (twenty degrees with the horizontal). The barrels are carefully finished with a reamer which is held to within five ten-thousandths of size. In the reaming, however, the barrels attain different degrees of heat and there may be slight variations in size. For this reason the throttles are each fitted individually on the original assembly. Therefore, when removing them, mark carefully so that each throttle is returned to the proper barrel with the proper face up and all points on the circumference in exactly the same location as before removal. The hexagon head idle adjustment holder should be unscrewed and the assemblies removed.

The economizers can be checked in place in the upper half and this is the preferable method. They should work together; that is, the positions should be relatively the same for each throttle position. When the throttle is closed, the economizer should be in the full "up" position with the port C showing approximately half open below the piston H. This is determined by the actual construction of the economizer, the upper piston L stopping squarely on a shoulder, and unless the economizer has had some major injury or derangement, this position will be found correct. The movement of the economizer is determined by the shape of the cam and as this is also accurately made and set at the factory, it will seldom be found incorrect. The movement of the economizer, including the operating lever should be free and easy. When the upper half is held in a normal position, the economizers should drop freely of their own weight. If it is desired to disassemble the economizer mechanism, the first operation is to remove the pivot screw G. This frees the lever F and the economizer assembly is then unscrewed from the bottom of the upper half as a unit.

Care should be taken to see that the economizer spring is not injured or altered. The tension in this spring is ample to care for the ordinary friction developed in operation but is held at a minimum consistent with this requirement so as to eliminate as much wear as possible from the cam

ever and operating roller. An excessive tension also tends to produce a tiff throttle action. On re-assembly the economizer must be returned to its proper location in the upper half and the adjustment made before it can be fastened in position. That is, the proper adjustment cannot be determined with the economizer removed from the upper half but must be made with all parts, including the cam lever, in their proper positions. The preferred method is to make the adjustment with all the units in place and functioning, and then to remove the economizer assembly for the fastening of the adjusting nut in place. Great care should be taken to see that all parts are properly fitted, that the moving parts are functioning freely and that there are no injuries or misalignments which will later give trouble. Each economizer should be returned to the side from which removed.

The re-assembly of the carburetor is of course just the reverse of the process given above. Too much care cannot be exercised in making it. Even slight defects, omission of any of the numerous gaskets, injury of gasket surfaces, inclusion of chips or dirt or any seemingly minor error may cause poor operation or a complete failure to operate. After the assembly of the lower half, the float level should be carefully checked following the directions given in the chapter on carburetors. This check should be made as nearly as possible under the exact conditions of head and with the same fuel as encountered in service. The wear on any part of the float mechanism is so minute that the float level will usually be found to be correct within the allowable tolerance, and resetting should be an uncommon necessity. When necessary, however, it should be changed without hesitancy, following carefully the directions given.

In assembling the upper and lower halves of the carburetor together, it should be made certain that they fit well. It will be noted that the venturi tubes are held in place by a shoulder machined on the tube itself fitting into a groove in the lower half. The thickness of the shoulder and the depth of the groove are nearly the same so that the venturis will be held tightly in place and will not move under vibration. There is a clearance of two to three thousandths of an inch left between the venturi diameter and the bore of the carburetor. In this particular model (the NA-Y7A) there are four parts (two venturis and two economizer guides) to fit closely into the four corresponding machined openings. It is obvious that the parts must be accurately sized and in perfect alignment if the halves are to go together properly and easily. Check carefully to see that the venturi shoulders will not hold the two halves apart, for should they do so, the resulting action will be the same as that from an imperfect main body gasket. The assembly of the two halves is best made by having the venturis in place in the upper half as the assembly is started, making certain that they are in the proper position to let the slots in the bottom fit over the main air bleeder arms.

Three points of vital importance in the re-assembly of the carburetors are: *The Main Body Gasket*: This should be in perfect condition. If the gasket is torn at any point around the float chamber or any of the mixture control drillings, it will not only allow fuel to seep out of the carburetor, but it will seriously interfere with the mixture control action. If torn or im-

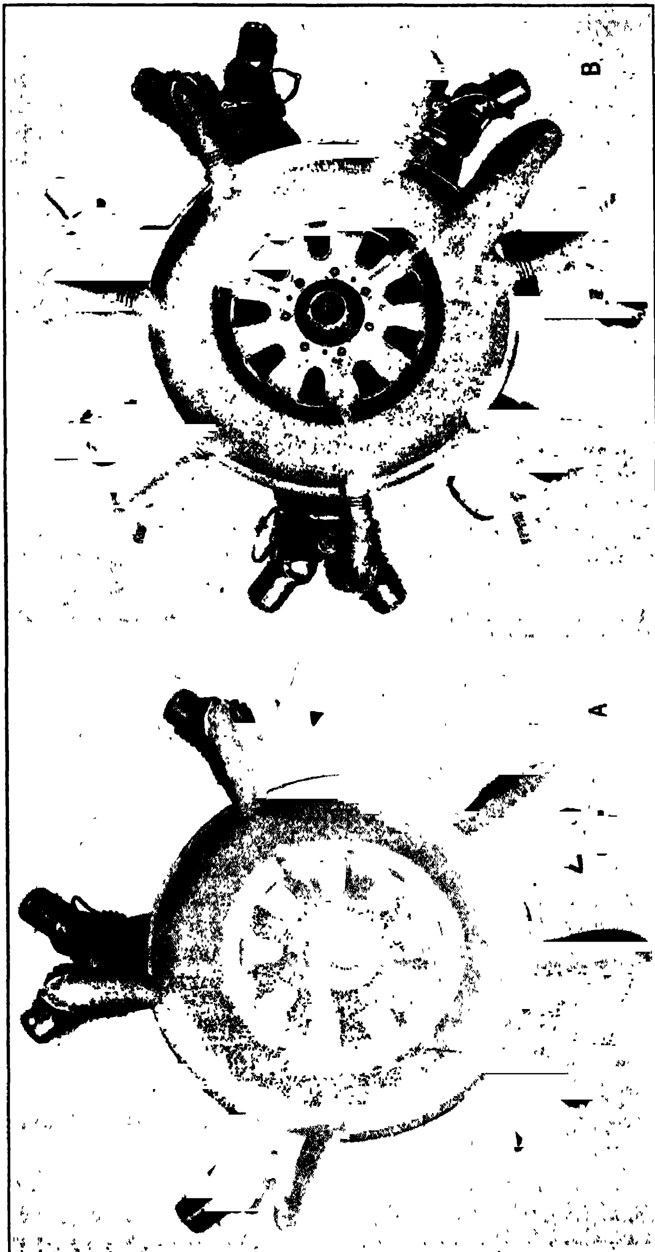


Fig. 616 A and B.—Views from Propeller End of New Series Wright J6 "Whirlwind" Engines. View at Left is the Five-Cylinder Rated at 150 Horsepower; at Right, the Seven-Cylinder of 225 Horsepower is Shown. Note Mounting of Exhaust Collector Ring in Front of Engine.

perfect around the idle tubes, it will cause poor idling operation and even cause the engine to cease firing entirely. If the gasket allows any connection between the idle tubes and the float chamber, the engine will not run between 600 and 1,200 r p.m. *The Idle Discharge Jets*: These should fit perfectly in place without forcing and should rotate freely. They are different in the right and left barrels and each must, of course, be returned to its proper side. *The Venturi Tube*: As previously covered, it is most essential that the carburetor halves fit securely and squarely together. If they do not do so, the trouble may be found in the venturi fit.

J6 "Whirlwind" Series.—The Wright "Whirlwind" engine has been improved and a new series has been announced by the Wright Aeronautical Corporation for production during 1929. The new line comprises three types which are illustrated at Figs. 616 A, B, C and D. The five cylinder is rated at 150 horsepower, the seven cylinder at 225 horsepower and the nine cylinder at 300 horsepower. Like the well-known J5 "Whirlwind," they are of the fixed radial air-cooled type operating on the four-cycle principle using domestic aviation gasoline. Differing only in respect to the camshaft and number of cylinders, the three models have such interchangeable parts as cylinders, pistons, connecting rods and crankshaft.

The brake horsepowers given here were obtained in air at 60 degrees Fahrenheit and 29.92 inches barometer. In each of the three models the maximum fuel consumption is .55 pounds per brake horsepower per hour at rated power and speed. Maximum oil consumption is .035 pounds per brake horsepower per hour at rated power.

Model	*cylinders*	*rated power*	*r.p.m.*	*weight dry*
R-540	five	150 hp	1,800	370 pounds
R-760	seven	225 hp	2,000	425 pounds
R-975	nine	300 hp	2,000	485 pounds

The above weights do not include starter, starting magneto, fuel pump or propeller hub. They do include carburetor, complete ignition system with dual Scintilla magnetos, magneto advance and retard mechanism, and oil pump.

Cylinders have a bore of five inches, and the pistons have a stroke of five and one-half inches, giving a compression ratio of 5.1 to 1. The total piston displacements of the three models are as follows: five-cylinder, 540 cubic inches; seven--cylinder, 756 cubic inches; nine-cylinder, 975 cubic inches.

Each engine is submitted to an acceptance test as follows: running in until ready for preliminary test. The preliminary test consists of two hours at 9/10 rated power. After this test the engine is disassembled for inspection and such corrections made as may be necessary. The engine is then re-assembled and submitted to a final acceptance test consisting of ½ hour at 9/10 rated power and ½ hour at full rated power. During the last ½ hour of this test, readings of power, fuel and oil consumption are made to demonstrate that the engine meets the guaranteed performance.

Besides being fifteen pounds lighter than its predecessor, the "Whirlwind" 9, the 300 horsepower model is also more efficient. Head resistance has

Aluminum alloy pistons, cross ribbed on the under side of the head and fitted with full floating hollow pins are employed. The wristpin, which has an average diameter of 7/8 inch, subject to certain tolerances, is held in place by expanding spring wire locks which prevent wearing the cylinder walls. Wristpins and cylinder walls are lubricated by oil spray from the crank and knuckle pin bearings. Piston heads are slightly concave in shape and this feature, in conjunction with the internal shape of the cylinder head, produces an almost perfect spherical combustion-chamber

As is usual in Wright engines, the connecting rods are alloy steel forgings and consist of a one piece master rod and the articulated rods Wristpin and knuckle pin bushings are of bronze pressed into the articulated rods and the crankpin bearing is of anti-friction metal, steel backed and pressed, and dowelled into the big end of the master rod.

The single throw, two piece crankshaft is made from alloy steel forgings and is counterbalanced to eliminate vibration. The crankshaft is drilled to provide oil passages giving positive pressure lubrication to the bearing surfaces. The overall length of the standard crankshaft is 21 1/32 inches.

The valve mechanism, including the push rods, is completely enclosed, and the housing for the rocker arms is cast integral with the cylinder head. Hardened steel cam followers operate through rollers of the same material running on the cam ring, and push rods of hollow steel tubing fitted with case hardened steel ball ends actuate the forged steel rocker arms. The rocker arms are carried on special ball bearings lubricated by the Alemite, or Zerk, pressure systems, and have provision for the adjustments necessary for correct valve clearances.

Tulip shaped valves of ample area are used with a solid stem for the inlet and hollow stem for the exhaust valves. The diameter of the inlet valve across the head is 2 3/8 inches and that of the stem is 1/2 inch. The exhaust valve diameter across the head is 2 3/16 inches and the diameter of the stem is 9/16 inch. Both inlet and exhaust valves have a lift of 9/16 inch. Three springs are fitted to each valve insuring reliability as the valve can be operated by any one of the springs. The valve springs are helical and are made from special heat treated spring steel wire.

Oil is forced to the rear of the hollow crankshaft by a pressure pump and is distributed to the bearings under pressure. Excess oil drains into a sump located in the main section of the crankcase between the bottom cylinders. From the sump, a single suction pump delivers the oil to the main tank in the plane, passing it through a strainer installed at a convenient point outside of the engine. By this means foreign matter is removed from the oil, and the strainer is accessible for frequent cleaning No external oil pipes are used in the lubrication system. This feature precludes the possibility of leakage from that source and prevents excessive chilling of the oil in cold weather. Oil pressure is regulated by an adjustable valve.

Two flange mounted Scintilla magnetos at the rear of the engines furnish ignition for the two separately connected sparkplugs in each cylinder Although the magnetos normally operate simultaneously, of course, the engines will operate on one magneto with but a slight reduction in speed.

A special Stromberg carburetor of the single barrel type, mounted on the rear section of the crankcase, supplies the mixture which passes from the carburetor to the "diffuser" chamber of the crankcase. This mixture is distributed evenly to all cylinders by the General Electric rotary impeller mounted in the diffuser chamber. This positive control of the mixture, obtained through the particular design of the rotary induction system, eliminates the vibration which would result from irregular mixture distribution. A "hot spot" is provided above the carburetor which thoroughly vaporizes the mixture. This feature serves to insure smooth operation of the engine when using any of the various types of gasoline. The temperature of the hot spot can be regulated from the pilot's seat in order to obtain maximum efficiency and fuel economy under all conditions. Provision also is made to obtain a supply of clean air to the carburetor at all times.

A fifteen ampere, fifteen volt Eclipse generator can be installed as optional equipment on the R-975 and R-760 engines. The first 500 of the R-540 engines, however, will have no provision for generators, according to the present plans. After 500 are produced provision may be made for generators depending upon the demand indicated by the sale of the first 500 engines While starting equipment is optional, an Eclipse Series six electric inertia starter is recommended for the R-975 engine, an Eclipse Series six hand inertia starter for the R-760 and an Eclipse hand starter Series 1-HB-6, with a booster incorporated for the R-540.

The specifications furnished by the manufacturer are as follows:

Type	Air cooled, four cycle, fixed radial
Number of cylinders (R-975)	9
Number of cylinders (R-760)	7
Number of cylinders (R-540)	5
Bore	5 in.
Stroke	5½ in.
Displacement (R-975)	975 cu in.
Displacement (R-760)	756 cu in.
Displacement (R-540)	540 cu in.
Compression ratio	5 to 1
Guaranteed hp at sea level (R-975)	300 at 2,000 r.p m.
Guaranteed hp at sea level (R-760)	225 at 2,000 r p m.
Guaranteed hp at sea level (R-540)	150 at 1,800 r p m
Guaranteed max. fuel consumption	.55 lb per hp hr at rated hp. and speed
Guaranteed max oil consumption	.035 lb per hp hr. at rated hp. and speed
Length overall without starter (R-975)	41 7/16 in.
Length overall without starter (R-760)	40 13/16 in.
Length overall without starter (R-540)	40⅝ in.
Diameter overall	45 in.
Weight dry (R-975)	485 lb.
Weight dry (R-760)	425 lb.
Weight dry (R-540)	370 lb.

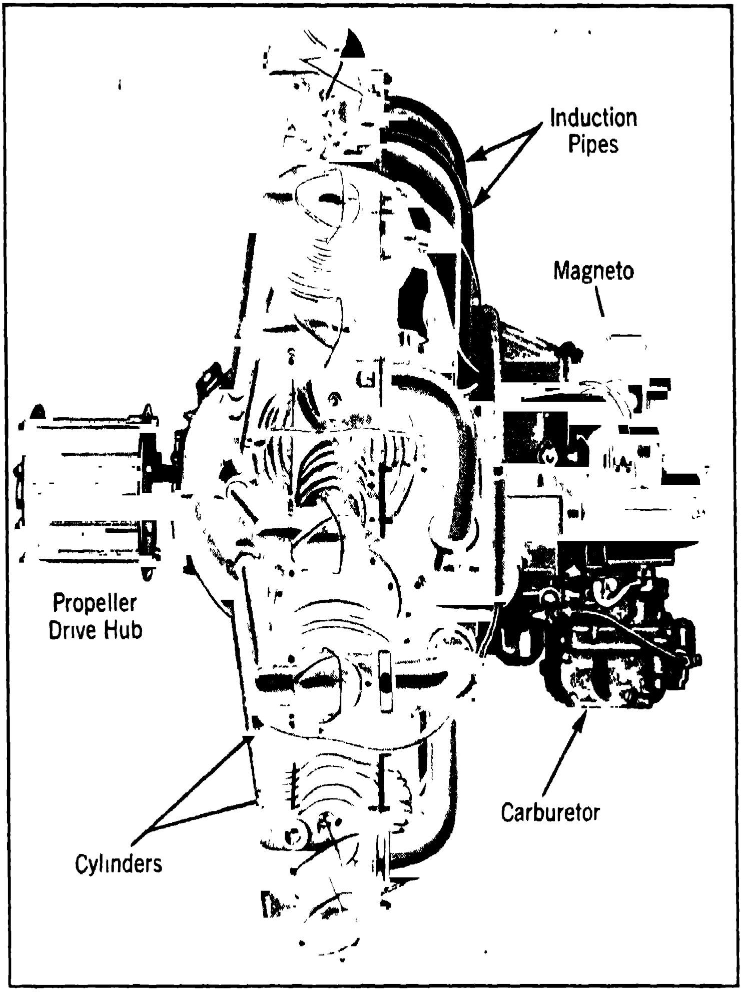


Fig. 617.—Side View of Pratt & Whitney "Wasp" Engine Showing Compactness in Design Made Possible by Radial Disposition of Cylinders.

QUESTIONS FOR REVIEW

1. What type of supercharger is used on Wright Cyclone engine?
2. What is the crankshaft construction of Wright Cyclone engine?
3. How does the Cyclone differ from the "Whirlwind" engine?
4. What is the Cyclone valve timing?
5. What are the main causes of rough running of Cyclone engines?
6. Describe flight operation of Cyclone engine.

CHAPTER XXXV

PRATT & WHITNEY "WASP" AND "HORNET" ENGINES

Description of "Wasp" Engine—Crankcase—Crankshaft—Connecting Rods—Cylinders—Valve Mechanism—Timing Gear—Accessory Drives—Lubricating System—Intake System—Accessories—"Wasp" Specifications—Wasp Engine Operation—Propeller—Fuel—Lubricating Oil—Proper Operating Conditions—Starting—Hard Starting—Ground Test—Rough Running—Oil Pressure—Oil Leaks—Treatment of New Engine—To Get Best Economy—Cold Weather Operation and Starting—Periodic Inspection—Storage of Engine—Top Overhaul—Disassembly—Inspection of Connecting Rods—Removing Valves—Valve Grinding—Inspection of the Pistons—Assembling—Running In—Repair Station Tool Equipment—Complete Overhaul—Taking Down Crankcase—Disassembly of Accessory Section—Floating Gears—Disassembling Crankshaft—Rod Disassembly—Miscellaneous Parts Disassembly—Clutch for Blower Drive—Assembling Clutch—Inspection for Clearances—Pistons—Cylinders—Gears—Replacement of Parts—Assembling the Engine—Safety Locking Devices—Blower Section—Rear Section—Connecting Rod Re-assembly—Crankshaft—Assembling Rods and Shaft in Case—Timing the Engine—Magneto Timing—Running In—Table of Fits, Wasp Engine—Description of the Hornet Engine—Operation—Inspection—Timing—Specifications, Hornet Engine—Table of Fits, Hornet Engine.

Description of the "Wasp" Engine.—The Pratt & Whitney "Wasp" engine has nine radial air-cooled cylinders of 5¾-inch bore and 5¾-inch stroke, and is rated 450 horsepower at 2,100 r.p.m when equipped for military use. Other ratings are specified for commercial operation, and in every case the rating of the individual engine is given on the engine nameplate. The unique features of this engine are its solid master connecting rod and two-piece crankshaft, the forged aluminum crankcase, enclosed valve gear, built-in supercharger, and the grouping of all accessories at the rear. These major features combined with painstaking manufacture make possible the "Wasp's" dependability and a high performance for the airplane with which it is equipped. Figs. 617 to 620 inclusive show the construction and external appearance very clearly. In this chapter the following definitions will be used: The propeller end of the engine will be called the front and the accessory end the rear. The direction of rotation of the crankshaft is anti-clockwise when viewed from the propeller. The cylinders are numbered consecutively in the direction of rotation beginning with the top cylinder, which is called No. 1. The right and left sides of the engine will be referred to as viewed from the rear.

Crankcase.—The main crankcase is divided into two similar sections in the plane of the cylinders and united by nine through bolts between the cylinders, as well as by the cylinder flanges. With this construction the explosion forces are equally distributed between the two main bearings, one of which is carried in each section of the case.

The NOSE, or front section of the case, is hemispherical in shape. It carries a deep row ball bearing which transmits the thrust of the propeller from the shaft to the engine mounting via the crankcase. The valve tappets are also carried in this section which encloses the cams and their operating

mechanism. The BLOWER or mounting section supports the engine in the airplane and is attached to the rear of the main case. The supercharger is carried in this section, together with its gearing. The mixture is fed into an annulus from the impeller and thence to the cylinders by means of tangential pipes. The rear or accessory section of the case is attached to the

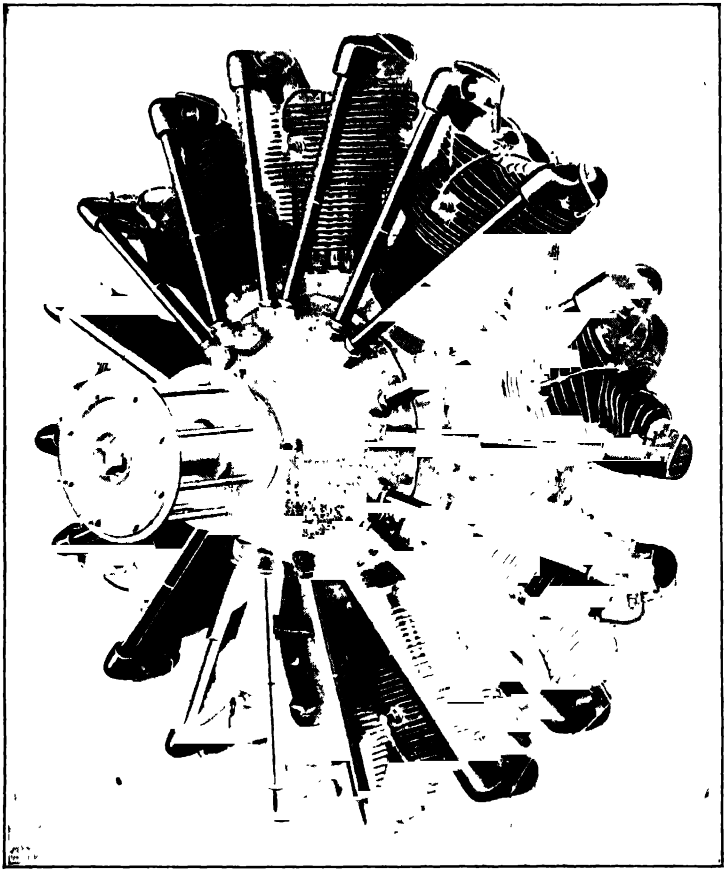


Fig. 618.—Propeller End of Pratt & Whitney "Wasp" Engine, a Nine-Cylinder Radial Air-Cooled Form.

blower section. It carries all the accessories, including two Scintilla magnetos, an Eclipse momentum starter, fuel pump, double Stromberg carburetor, oil pumps, strainer, relief valve, tachometer drive, and two synchronizer drives. Provision is also made for mounting and driving a generator. The blower and rear sections of the case form an assembly and may be removed from the main case as a unit, without disturbing any of the accessories or their gearing. Likewise, the main and nose sections may be removed as a unit with the cylinders in place, leaving the blower and rear sections in the airplane. The sectional views at Figs. 621 and 622 show the

mechanical details clearly.

Crankshaft.—The single throw, two-piece crankshaft is supported on three bearings. There is one roller bearing on each side of the crankpin, and the third, a ball bearing, just behind the propeller hub, takes the propeller thrust as well as radial load. To assemble the single piece master rod the shaft is divided into a forward and rear section which transmits the power to the propeller hub carried by it. The rear section telescopes into

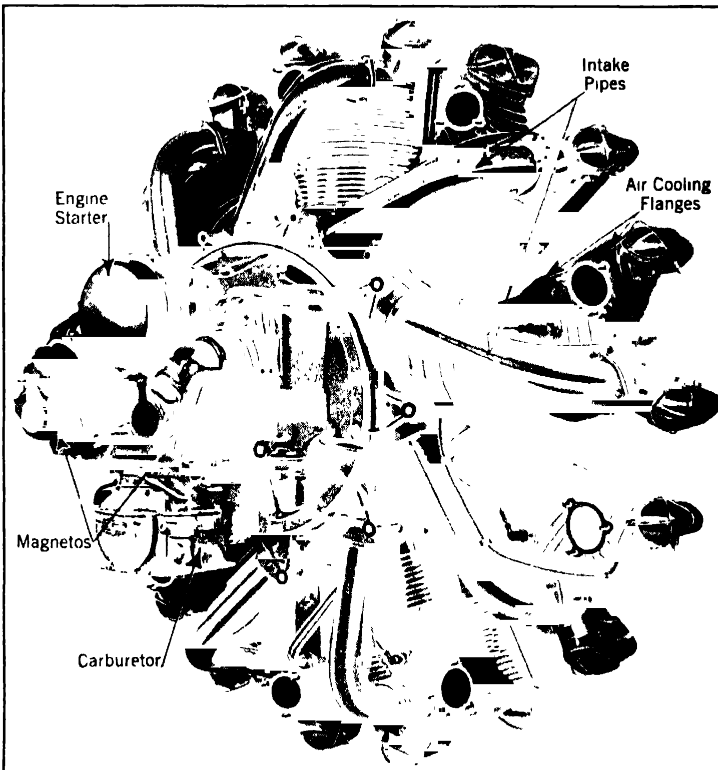


Fig. 619.—Pratt & Whitney "Wasp" Engine Viewed from Accessory End.

the crankpin, and is carried completely through it. The two sections are united by a through bolt and kept in the proper angular relation by splines. The sectional view at Fig. 621 shows the relation of the shaft to the rest of the engine and the crankshaft parts as they appear when that member is taken down are shown in photographic reproduction at Fig. 623.

Connecting Rods.—The master connecting rod has a solid instead of detachable cap big end. This construction makes possible high crank speeds which have been impossible with the two-piece rod. Babbitt-lined big end bushings are inserted in the rod and bear directly on the crankpin. Eight I section link rods are attached to the master rod by means of knuckle pins. Each rod is bronze bushed for the piston and knuckle pins. Oil is

carried under pressure to the big end bearing, and also to the knuckle pins.

Cylinders.—The cylinder barrels have integral fins and are machined from steel forgings. Each barrel is screwed and shrunk into a cast aluminum cylinder head following the usual high class construction. This is a permanent joint and cannot be disassembled. Each cylinder has one inlet and one exhaust valve, seating on bronze inserts which are shrunk into the head casting. The proper cooling of the exhaust valve seat and stem is of great importance, especially in an air-cooled engine. The Pratt & Whitney engine has the valve gear housed in extensions cast on the cylinder

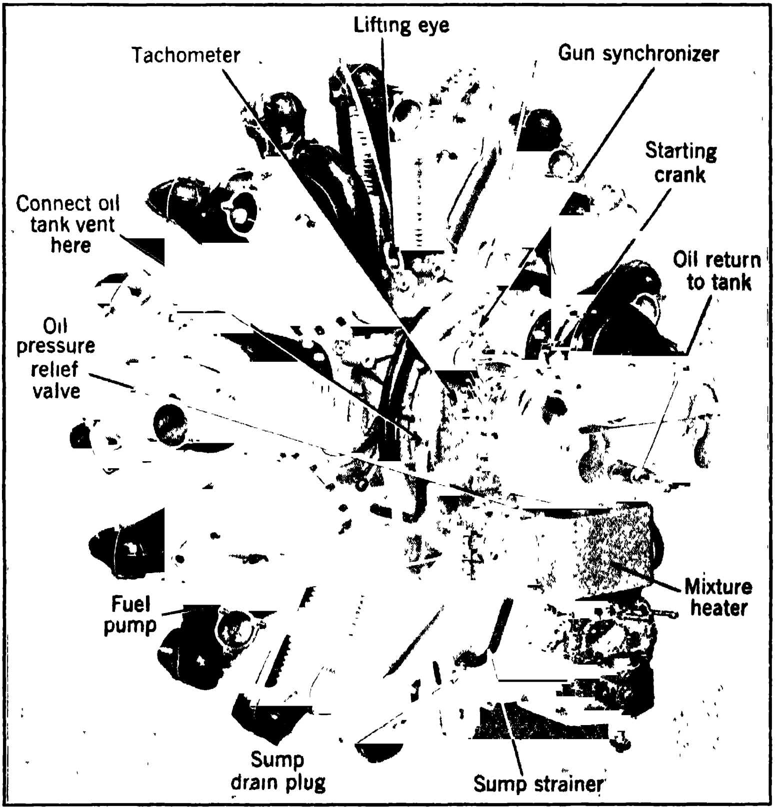


Fig. 620.—Pratt & Whitney "Wasp" Engine Viewed from Anti-Propeller End Showing Where Various Items of Piping are Attached, Location of Oil Strainers, Etc.

head. These parts form additional radiating surface, and the one on the exhaust side is provided with cooling fins. As a result of this construction, valve grinding is said to be necessary no oftener than every 200 to 300 hours of service.

Valve Mechanism.—All valve operating parts are enclosed. The rocker arms are supported by ball bearings in the rocker housings which are part of the cylinder head. The eighteen tappets are located in the front section

of the crankcase and actuate the rocker arms through tubular duralumin push rods which have hardened steel ball ends. These rods are enclosed by telescopic covers held in place by springs. The cover tubes can be collapsed by hand, and bayonet locks are provided to retain them in this condition while they are being removed. Each rocker housing has a removable cover held in place by a spring bail. These covers and the push rod covers and push rods can be removed without special tools. Two concentric valve springs are used, secured to the valve stem by a split cone and washer. Inlet and exhaust valve springs are interchangeable. The valve springs can be removed without taking out the rocker arms. After the push rod is taken out, the rocker arm can be tipped up far enough to allow the valve springs to pass. The valve clearance adjusting screw is in the end of the rocker arm over the valve. A half ball is used between the adjusting screw and the valve stem to minimize friction at this point.

Timing Gear.—The cams, which actuate all the valves, run on a sleeve on the crankshaft as shown in sectional view at Fig. 621. A train of spur and internal gears drive the cams at 1/8 crankshaft speed in the opposite direction to the crankshaft rotation. The cam drive gear on the crankshaft is not keyed to the crankshaft, but to the sleeve on which the cam itself rotates. The front end of this sleeve has a large number of serrations which mesh with similar serrations on the rear end of a sleeve which carries the propeller thrust bearing. These two set of teeth are normally held tightly together by the thrust bearing nut. When the engine is being timed, however, this nut is slacked off, the two sleeves are slightly separated as shown at Fig. 624 and the cam can then be turned by a special wrench which has teeth to engage with one of the cam drive gears. After the adjustment is made, it is locked by screwing up the propeller thrust bearing nut.

Accessory Drives.—The accessories are driven by three lay shafts which extend entirely through the blower and rear sections. Each shaft carries a spur gear at its forward end, which engages with a gear attached to the rear of the crankshaft. The upper shaft provides a drive for the momentum starter and a generator if used. Each of the two lower shafts drives a magneto at its rear end, through a readily adjustable coupling. Besides this, two vertical drives are provided for by a bevel gear on each shaft. The upper drives are for two gun synchronizers and two tachometers, while the lower drives an oil pump on the right side and a fuel pump on the left. The supercharger impeller shaft is in line with the crankshaft and driven from it at high speed by two pairs of spur gears.

Lubricating System.—The oil pump assembly consists of two gear pumps, one supplying oil under pressure to the engine bearings, and the other for scavenging. Oil is taken from the tank by the pressure pump, and after passing through a strainer located just forward of the carburetor is carried through the blower section, down into the sump and thence up into the hub of the cam drum in the nose of the engine where it is fed into the crankshaft. A relief valve to regulate the oil pressure is located beyond the oil screen just off the strainer chamber. The crankpin bearing, knuckle pins, cam drum, cam drum pinion shaft, accessory shafts, and the supercharger gearing are all lubricated by oil under pressure. Oil is taken from the strainer chamber by drilled passages to lubricate the accessory

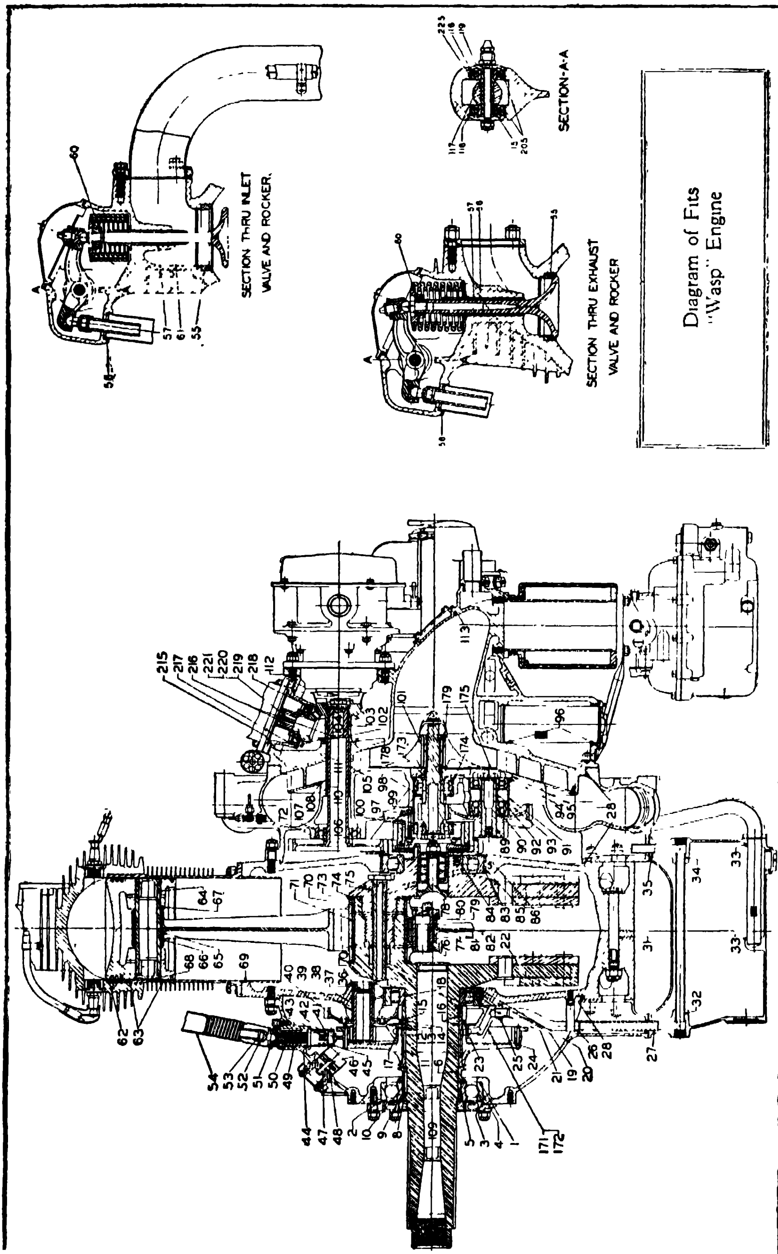


Fig. 621.—Sectional Diagrams Showing Numbered Parts to Serve as Key Numbers for Tabulation of Fits and Clearances; also Construction of "Wasp" Engine.

drives. All the other engine parts are provided for by the mist or spray from the pressure oiled parts except the rocker arms and the magnetos. The surplus oil drains into a sump carried between cylinders No. 5 and No. 6, from which it is returned to the oil tank by the scavenging pump. The discharge or warm oil is carried in a jacket around the carburetor elbow to prevent the throttles freezing.

There is an external Alemite nipple on each valve rocker housing, and lubricant applied here supplies the rocker bearing and also reaches the push rod socket through a hole drilled in the rocker. There is also a similar nipple in each valve adjusting screw, to lubricate the half ball which bears on the valve stem.

Intake System.—A double barrelled Stromberg carburetor is used. The engine has provision for driving a C-3 or C-5 Air Service type fuel pump which can be supplied, with both an integral pressure regulating valve and bypass valve for the hand pump The mixture is taken from the carburetor and delivered to the cylinders by means of a General Electric centrifugal supercharger. The fuel pump, carburetor, and supercharger are located at the rear of the engine. A mixture control is provided which is effective to 25,000 feet.

Ignition.—Ignition is furnished by two nine-cylinder Scintilla magnetos located at the rear of the engine, each firing sparkplugs in all nine cylinders, thus giving two independent sources of ignition. A Splitdorf hand booster magneto is furnished for starting ignition.

Starting.—An Eclipse momentum starter can be furnished. Energy is stored in a small fly wheel running at high speed which furnishes power to start the engine. This equipment is capable of turning the propeller from four to six complete revolutions on one winding.

Equipment.—Each engine is supplied with carburetor, running magnetos, hot-spot mixture heater, propeller hub attachment parts, tool kit, starting magneto, primer pump, magneto switch, nine exhaust flanges and gaskets, instruction book, and shipping box. Other accessories which can be furnished include: Hand or electric starter; generator; fifteen Amp., fifteen volt, or 25 Amp., fifteen volt; fuel pump; propeller hub; gun synchronizer drives; radio shielding.

A Splitdorf hand operated booster magneto is provided for starting and should be wired to the trailing brush connection (marked "H") on one of the main magnetos. The base or frame of the hand magneto must be grounded or connected to the engine crankcase in order to get the best results. A magneto switch is supplied and has a connection for grounding the starting magneto as well as the main magnetos. This must be connected as a safeguard against accidental starting. Seven millimeter wire is used for high tension connections.

Inspection Facilities.—The cowling forward of the firewall should be easily removable, and large inspection doors are desirable in each side of the cowling just forward of the firewall to give access to the magnetos, oil strainer, etc.

Controls.—The location and movements of the throttle, mixture control, and spark timing control, are shown on the installation drawing at Fig. 625.

Exhaust Pipes.—The exhaust port flanges furnished with the engine are intended to be welded to 2½ inch O.D. steel tubing.

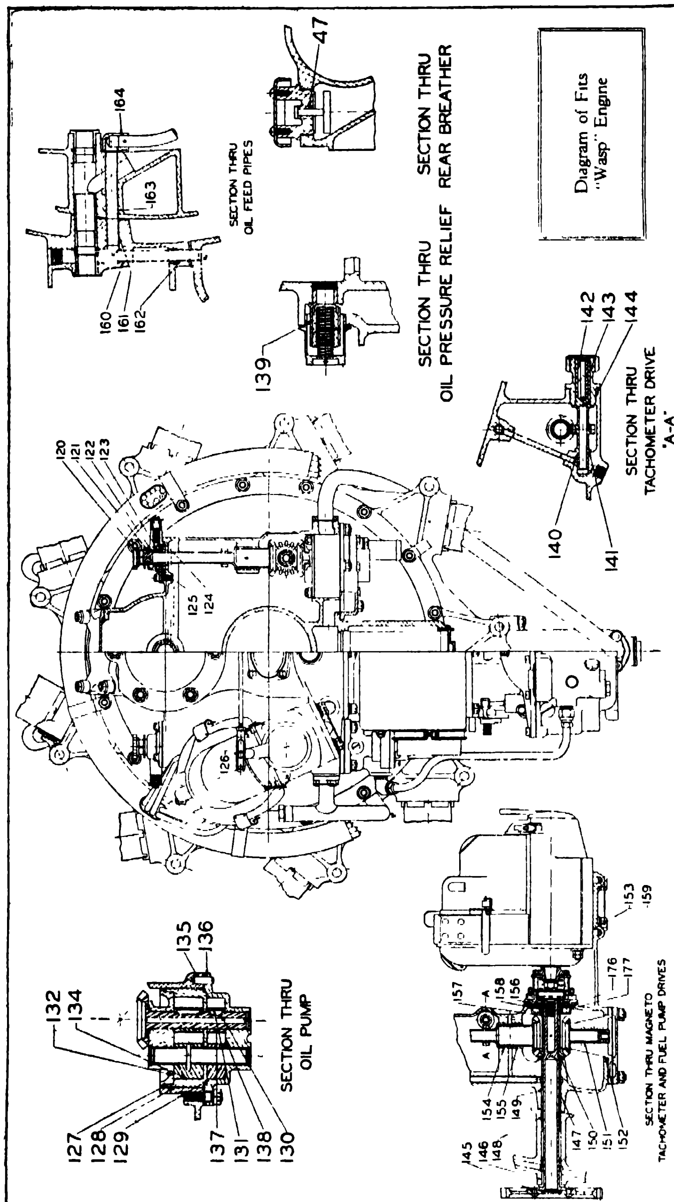


Fig. 622.—Sectional Diagrams of "Wasp" Engine Parts Giving Key Numbers to Accompany Tabulation of Fits and Clearances in Text.

Tachometer Drive.—Provision is made for two tachometer drives, one on each side of the engine. The connections are threaded to take the standard swivel head so that the shafts can be brought off in any desired direction. The driving spindles rotate counter-clockwise, looking at the engine, and run at one-half crankshaft speed.

Starter.—The starter usually used is the Eclipse Machine Company's Model M1,932. The starting crank is detachable and requires an outboard support or bearing where it passes through the cowling. The location of this support is shown on the installation drawing. A rigid rod to pull the starter trigger should be carried to the cockpit. This has to be pushed to disengage the starter, if a start is not accomplished.

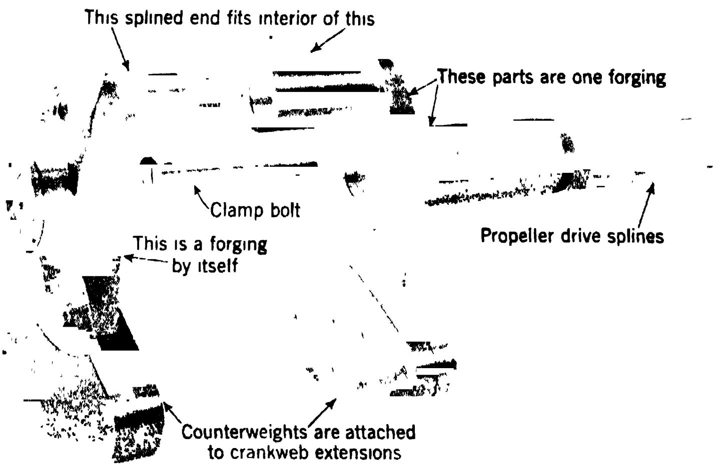


Fig. 623.—The Pratt & Whitney "Wasp" Crankshaft Taken Apart to Show Parts Comprising the Assembly.

"WASP" SPECIFICATIONS

Model	**R—1340—B**
Rating (Military)	
Rated Power (doped fuel)	450 h.p.
Rated Speed	2100 r.p.m.
Rating (Commercial)	
Fuel: Grade B, domestic aviation gas of sp. gr. .682 or less	
Rated Power	400 h.p.
Rated Speed	1900 r.p.m.
General Form	
Cylinder arrangement	Radial
Number of cylinders	9
Cooling	Air
Bore	5.75"

Stroke	5.75"
Piston displacement	1344 cu. in.
Compression ratio	5.25 : 1
Overall Dimensions	
Outside diameter	50⅝"
Mounting bolt circle diameter	23⅜"
Total length	43⅜"
Length back of mounting	14¼"
Distance from mounting to C. L. of propeller	23 7/16"
Crankcase	
Material	Aluminum
No. of sections	5
Crankshaft	
Type	Single throw, two piece
Main Bearings	Ball or Roller
Thrust Bearing	Ball Type
Master Rod	
Type	One piece
Form of shank	I- section
Link Rods	
Form	I section
Cylinders	
Barrel	Steel
Head	Aluminum
Cooling fins	Integral
Valves	
Number per cylinder	2
Material, inlet	Tungsten or Silchrome
Material, exhaust	CNS
Lift, inlet	9/16"
Lift, exhaust	9/16"
Diameter inlet port	2⅜"
Diameter exhaust port	2⅜"
Valve Timing	
Inlet opens	26° early
Inlet closes	76° late
Exhaust opens	71° early
Exhaust closes	31° late
Valve Springs	
Number per valve	2
Form	Helical
Oil Pump	
Type	Gear
Number of sections	2
Oil pressure	75-100 lbs.
Magnetos	
Make	Scintilla
Number	2
Type	AG 9-D
Timing (full advanced)	30°
Direction of rotation	Clockwise

Sparkplugs

Type	B. G. Midget No. 4
Thread	18 m/m

Tachometer Drive

Type	A. S Standard
Number	2
Rotation	Counter-clockwise
Speed	½ crankshaft

Supercharger

Make	Gen. Electric
Type	Centrifugal

Carburetor

Make	Stromberg
Type	NA-Y7A

Carburetor Setting

The test log sheet shipped with each engine gives details of jet and choke sizes for the individual engine.

Standard Equipment and Weight

Weight of Wasp, with magnetos and carburetor, but no extras	670 lbs.
The following accessories are shipped with each engine (weights not included in above)	
Starting magneto (Dixie 100)	8.3 lbs.
Primer	.5 lbs.
Magneto switch	9 lbs.
Heater	10.0 lbs.
Tool Kit	11.9 lbs.

Additional Equipment

The following accessories can be supplied:	
Fuel pump (C-5 type)	2.7 lbs.
Hand starter eclipse type M-1932, including crank	24.1 lbs
Propeller hub for metal blades	26.2 lbs.
Gun Control Drive, as specified	

Shipping Data.—Overall size of box, 56 inches by 56 inches by 50 inches. Weight, boxed, 1,175 pounds approximate. The method of bolting the engine to a carrier and afterwards securing that member in one half of the packing case is clearly shown at Fig. 627. The packing case is made in two halves, held together by substantial iron bands. The method of removing the engine from the packing case after the top half has been removed is clearly shown in the illustration the special sling attaching to lifting hooks provided for the purpose.

Wasp Engine Operation.—For satisfactory operation it is essential that the engine be properly installed. In general, this is covered in the chapter headed "Installation" which gives the instructions for a number of engines, similar in general construction. A typical Wasp installation in a Vought Corsair fuselage is shown at Fig. 628. Aside from the proper installation, it is of the utmost importance to have the proper propeller setting, as well as the correct fuel and lubricating oil.

Propeller.—The propeller must be set so that it will hold the engine to its rated speed at full throttle in level flight near the ground. It has been found in some cases that operators accustomed to slower speed engines

have set their propellers in such a way as to restrict the maximum r.p.m. of the engine to considerably less than the rated speed. This is very detrimental and is extremely likely to cause trouble from detonation, etc., since the carburetor setting and valve ignition timing have all been adjusted for the rated speed. It is equally dangerous to set the propeller to turn more than the rated speed in level flight, and we cannot be responsible for engines operating under these conditions.

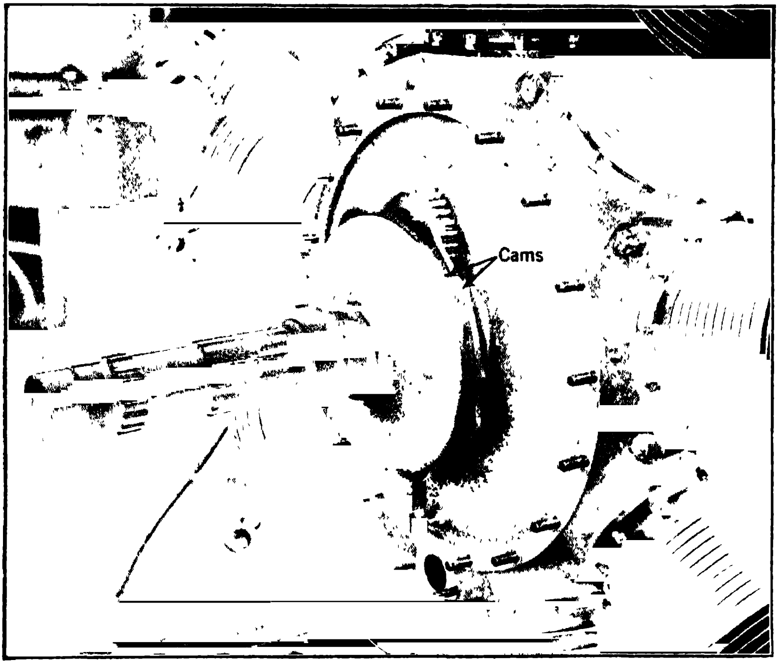


Fig. 624.—View Showing "Wasp" Cam and Serrated Cam Driving Discs Separated to Permit Accurate Cam Timing.

Fuel.—The best grades of fuel should always be used. The difference in expense between good and bad fuel for the operation of the "Wasp" or "Hornet" engine is a very small percent of the total cost of operating the airplane. It will be found that the difference in cost will be more than made up by freedom from trouble, increased power and lower consumption. The commercial "Wasp" and "Hornet" engines are designed to operate on Grade "B" domestic aviation gasoline or its equivalent. Unfortunately, no satisfactory means has been devised to determine the anti-knock value of fuel. This, rather than anything else, is the determining factor. In general, gasoline made from West Coast crude is the best, as it detonates less than East Coast or Mid Continent fuel. Under no conditions should the engine be operated on ordinary automobile gasoline at full throttle. As an emergency measure it is possible to fly a lightly loaded ship at part throttle on automobile gasoline. It will be found entirely satisfactory to

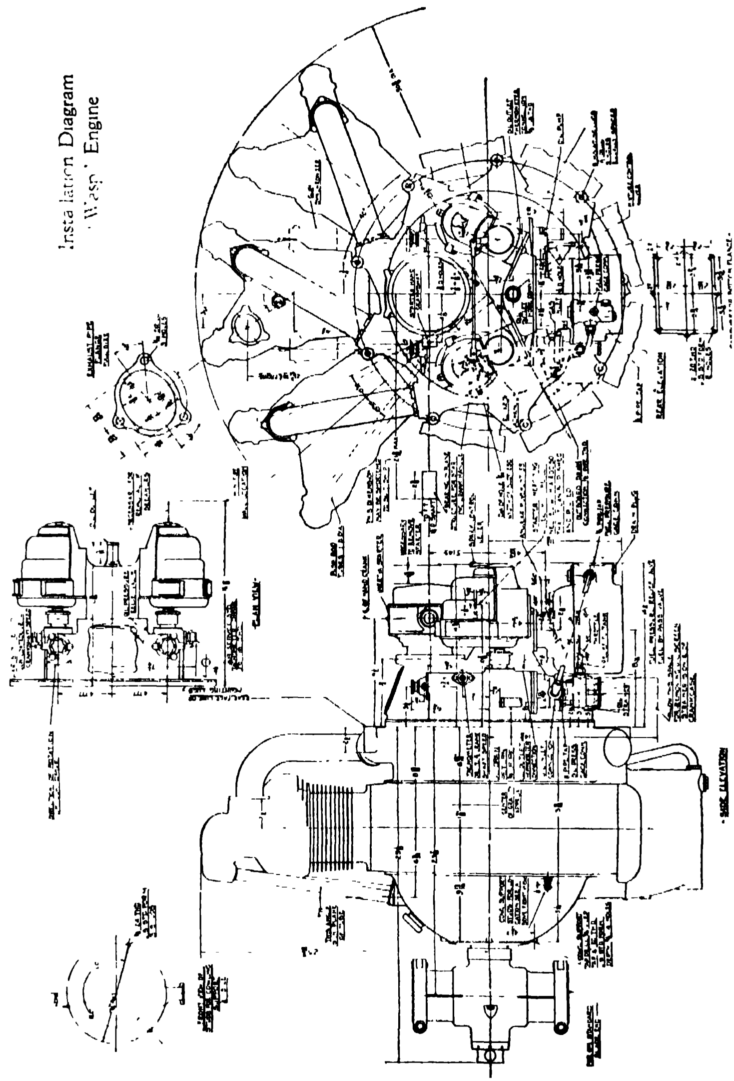


Fig. 625.—Installation Diagram of Pratt & Whitney "Wasp" Engine.

use fifteen to twenty per cent of benzol with any Grade "B" fuel which otherwise would detonate. Commercial 90 per cent benzol is all right for this purpose if free from acid, and it should conform to U. S. Army Specification 2-58. The use of tetraethyl lead is not recommended on account of its effect on the valves and sparkplugs. If this is used, not more than four cubic centimeters of ethyl fluid should be used per gallon of gas. It is important to mix the material thoroughly, and it is best to stir the ethyl fluid into five gallons of gasoline and then pour this mixture into the fuel

tank which has already been partly filled. Considerable damage can be done if the fuel is not properly mixed.

In general, a fuel should meet the following specifications: Baumé gravity not heavier than 72 degrees. Fifty per cent should distill off at not over 221 degrees Fahrenheit, and the end point should not be over 374 degrees Fahrenheit. A rough and ready method for arriving at the relative value of different fuels for aircraft use is to compare the temperatures at which 50 per cent distills off. The lower the temperature the better the fuel, and these figures will give some indication of the anti-knock properties of the various samples. The use of low grade gas will cause uneven distribution and overheating. Damage to the engine is sure to ensue. Furthermore, the fuel consumption in gallons per hour is likely to be considerably less

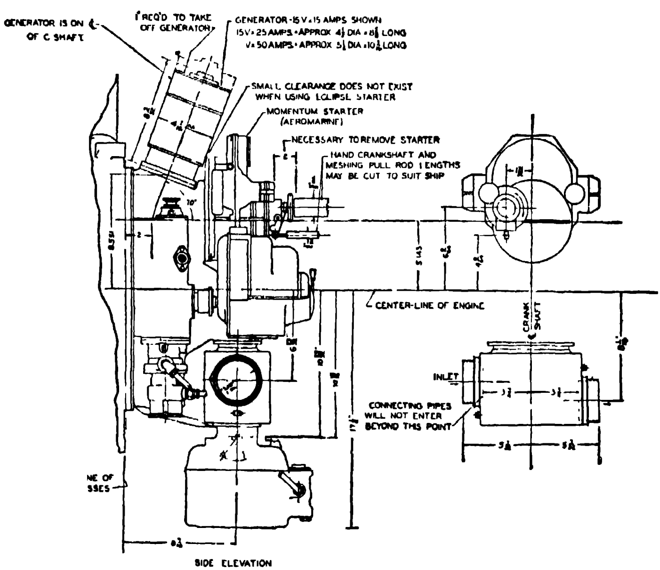


Fig. 626.—Rear Elevation, Pratt & Whitney "Wasp" Engine Showing Starter and Hot Spot Heater.

with the higher grade fuel. For the operation of engines on the military rating, either Grade "A" domestic aviation gasoline should be used, or Grade "B" with fifteen per cent benzol, and in an emergency Grade "B" with four cubic centimeters of ethyl fluid per gallon.

Care should be taken to see that the fuel has no water or foreign matter in it, which can be accomplished by straining it through chamois. Precautions of this kind often eliminate forced landings. The makers will be glad to advise all engine users on the matter of the proper fuel. In writing for information they should be furnished with a distillation curve of the proposed fuel and a statement as to the source of the crude from which it is refined.

Lubricating Oil.—It will be found that the very best lubricating oil will be much the cheapest in the long run. It is essential that oil of the proper viscosity be used, that it be free from acid, have a low cold test, and leave the minimum amount of carbon in the combustion-chamber. Improper oil is likely to result in low oil pressure, high oil temperature, the formation of considerable carbon and excessive oil consumption. If the engine is operated under extreme conditions of temperature, two grades of oil will be necessary. The grades required will depend a great deal on the make of the oils. The engine builders will be glad to advise users in regard to this. For ordinary conditions with air temperatures of 40 degrees to 90 degrees Fahrenheit, the following specifications have been found suitable:

Flash Point (open cup)	465° F. min.
Burning Point	520° F. min.
Viscosity (Saybolt)	105-115 at 210° F.
(corresponds to S.A.E. Viscosity No 60)	
Specific Gravity	.886
Cold Test	40° F. (lower if possible)

For cold weather, below 40 degrees Fahrenheit it may be found advisable to use an oil one grade lighter than the above, having a viscosity of 90-100. However, certain oils are now on the market which combine the desirable qualities of high viscosity and low cold test. For extremely hot weather, over 90 degrees Fahrenheit, a heavier oil is usually necessary. Chemical tests should be made from time to time to make sure the fuel and oil continue to meet the specifications. Great care should be used in handling the lubricating oil to prevent dirt being collected in it, as this will act as a grinding compound in the engine. The oil storage should be kept covered at all times, and the oil measures and funnels cleaned before each using. It has been found good practice to change the oil every fifteen or twenty flying hours. When filling the oil tank after it has been drained, turn the propeller over by hand or with the starter several complete turns, in order that the oil piping and pump will be thoroughly primed.

Proper Operating Conditions.—Propeller speed, full throttle on the ground, usually 150 to 200 revolutions less than level flight, depending on propeller design. Propeller speed, level flight—the same as the rated speed of the engine within 50 revolutions, plus or minus. Desired oil outlet temperature, 60 degrees Centigrade or 140 degrees Fahrenheit. Maximum oil outlet temperature, 75 degrees Centigrade or 170 degrees Fahrenheit. Desired oil pressure—75 to 90 pounds. Minimum oil pressure, 60 pounds. (For all speeds above 1,200 r.p.m.) Oil Consumption, cruising at 1,700 r.p.m., between one and two quarts per hour. Desired (minimum) fuel pressure, two pounds. Maximum fuel pressure—four pounds.

Starting.—Retard the spark one-third, set the mixture control full rich, crack the throttle slightly open, about one-half inch on the quadrant, and turn the ignition switch to the "On" position. Make sure the fuel supply is turned on and pressure pumped up with the hand pump to at least three pounds. Close the adjustable nose shutter as shown at Fig. 628, insert the starting crank and wind up the starter. There is little danger of cranking the starter too fast. Enough energy should be stored up to crank the engine

at least two or three complete revolutions. This takes about a minute and the starter speed necessary will be learned after one or two trials. When starting stone cold, prime the engine with three or four complete strokes of the priming pump. Pull the primer plunger back slowly to obtain a full charge and push it back in rapidly to atomize the fuel. Be sure and shut off primer valve as engine may otherwise be flooded. When the starter has been wound up, quickly buzz the hand magneto and pull the starter trigger. If everything is in good condition, the engine should start immediately even in cold weather. As soon as the engine starts, advance the spark.

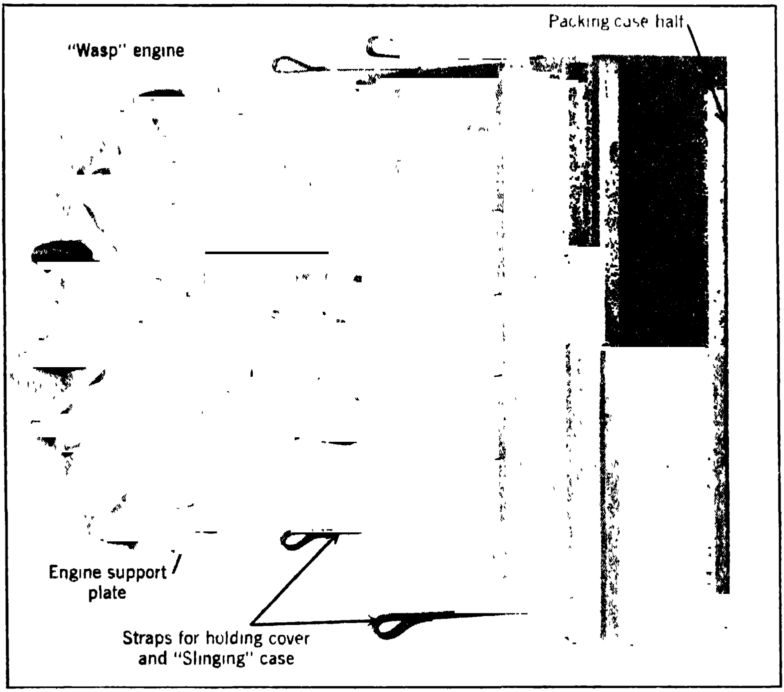


Fig. 627.—Showing Method of Removing Pratt & Whitney "Wasp" Engine from Packing Case. Note Plate to Which Engine is Bolted for Shipment.

When the engine is warm, two or three strokes of the primer will be enough. If the engine does not start immediately, do not keep priming but find out what is wrong. Excessive priming washes the oil from the cylinder walls and is very likely to cause scoring of the pistons and cylinders. The primer fuel supply should be shut off as soon as the engine starts.

If the engine fails to start, check to see whether the switch is on, the throttle is just cracked open, the mixture control is set full rich and that there is actually fuel at the carburetor and at the primer; also that the starting magneto gives a good spark at the running magneto. If the starter runs down before the engine starts, the starter jaw will be left in engagement. Before the starter can be rewound, it is necessary to disengage the

jaw, either by pushing in the starter trigger or by turning the propeller forward a short distance.

Idling Adjustment.—On a new installation there are two adjustments to be made to obtain proper idling. Mixture regulation for idling is obtained by moving the two small lever on the front side of the carburetor. These are moved toward each other to richen and farther apart to lean the mixture. The adjustment should be made when the engine is warm and should be as rich as possible and still have good operation while warm. To adjust the idling speed, the set screw in the throttle lever is turned. Slower idling may be permitted with a heavy propeller than with a light one. Do not slow the engine down so much that it is in danger of stalling.

Hard Starting.—An engine in good condition should start promptly regardless of the air temperature, providing the above instructions are carefully followed. Hard starting is often found to be caused by leaky primer lines or primer pump packing. All primer connections should be kept tight and the pump packing properly adjusted. In some installations it is necessary to operate the wobble or hand fuel pump while priming, as otherwise the primer may not receive any fuel. Another frequent cause of hard starting is that a strong spark does not reach the running magnetos from the starting magneto. This can be readily checked by removing the high tension lead from the hand starting magneto and trying it on the engine, and at the same time turning the starting magneto crak. The spark should jump from ¼ inch to ⅜ inch without difficulty. If it does not, it is likely that the insulation on the high tension wire has been damaged, or that a proper ground has not been provided between the hand starting magneto and the engine.

Ground Test.—After starting, run the engine slowly, in order to warm it up gradually, until the oil temperature has reached 100 degrees Fahrenheit or 40 degrees Centigrade. After the oil has been warmed up, the engine should be gradually brought up to full throttle. Before doing this, be sure the wheels are properly blocked and the stick pulled back. With the throttle wide open, try both magnetos with the switch, observe whether the fuel pressure is between three and four pounds and the oil pressure from 75 to 100 pounds, also the propeller speed. For ships equipped with propellers permitting a level flight propeller speed of 1,900, the ground speed of the propeller will be between 1,500 and 1,650 r.p.m. depending upon the type of the propeller used. Do not operate the engine at full throttle on the ground for more than a moment or two. Continued running under these conditions is unnecessary, and will result sometimes in damaging the engine. In some installations the effective part of the propeller blades is so far removed from the crankshaft that insufficient cooling is provided for the engine while the plane is at rest, although the installation may be perfectly satisfactory while in the air. Open the nose cowling shutters before taking-off.

Rough Running.—The usual cause for rough running, providing the ignition is functioning correctly and the carburetor is properly adjusted, is an unbalanced or fluttering propeller. The "Wasp" engine is carefully balanced at the factory and should run very smoothly. If it does not, the propeller should be inspected. First, if it is a metal propeller, the angle of

the blades at the same station should be carefully checked on a surface plate with a protractor. Next, it should be balanced on a mandrel and tracked. After this inspection, the blades should be observed for flutter while running at full speed on the ground. This condition may not exist at low engine speeds, but becomes pronounced at full throttle. The substitution of a propeller from another ship which is known to run smoothly will sometimes be found a convenient check of this situation.

Oil Pressure.—Oil pressure should register immediately after starting. If there is no indication on the oil pressure gauge after 30 seconds, stop, check up the oil supply, and especially the oil suction pipe connections. A very small leak in the oil suction line will prevent the oil pump from working properly. Do not continue running the engine unless oil pressure is obtained. The normal operating pressure is 75 pounds at 1,800 to 1,900 r.p.m. and at least 25 pounds idling.

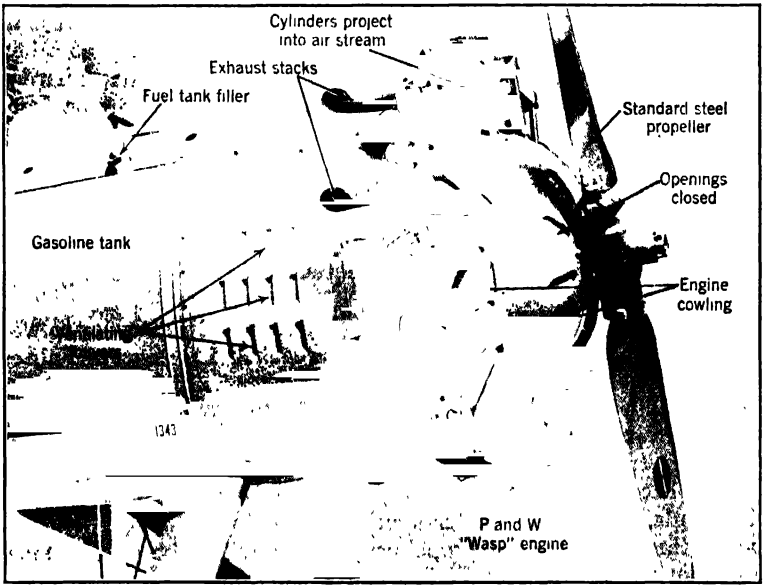


Fig. 628.—Front of Vought "Corsair" Airplane Fuselage Showing Pratt & Whitney "Wasp" Engine Installed. Note Cowling with Variable Opening Shutter in Front of Engine.

Low oil pressure is usually due to an air leak in the line from the oil tank to the pressure pump. For this reason the connections should be carefully checked. Be sure that an adequate amount of hose, at least an inch, overlaps both the pipe and the connection on the engine, in order to have sufficient area for the hose clamp. No adjustment is provided for the oil pressure, as low pressure indicates trouble in the lubricating system which cannot be corrected by a new adjustment of the relief valve. If the connections are tight and the proper kind of oil used and still the pressure is low, it may be due to a loose cam bearing or a loose master rod bearing.

These two possibilities are very unlikely, and should be investigated only after all other possible causes have been considered. Excessive oil consumption and fouling of sparkplugs may be due to an air leak in the pipe which takes oil from the sump to the suction pump on the engine. This will prevent proper scavenging of the crankcase. See if the flanged joints have good gaskets and are bolted up tight.

Oil Leaks.—Particular care has been taken in the design and manufacture of the "Wasp" engine to insure its being oil tight. Leakage is an indication of trouble and consequently should be investigated. For this reason it is strongly recommended that the engine be kept clean, so that any oil leakage may be noticed and readily traced to its source.

The mixture control should be kept at "Full Rich" for all flying below 5,000 feet, especially when landing. The mixture control should be used above 5,000 feet, being careful to adjust it so that the maximum r p m. is obtained. This can best be done by flying level with the throttle in the fixed position, and observing the tachometer.

Treatment of New Engine.—Careful treatment of a new engine prolongs its life, and is just as necessary as proper driving of a new automobile. Each engine is run approximately fifteen hours at the factory before it is shipped, and it is thought that a total of at least 25 hours careful running is desirable. During the first ten or fifteen hours of operation in the plane it is well to warm up the engine gradually after each start, and to stop gradually also, rather than shut off suddenly from full speed. During this period the engine should not be run wide open any more than absolutely necessary and sudden acceleration should be avoided. The same precautions apply to some extent at any time during the life of the engine.

As a further aid in running a new engine, it is recommended that a pint of oil be added to each ten gallons of gasoline for the first ten hours of operation. These measures, together with careful attention to maintaining the proper oil pressure and frequent change of oil, will result in polishing all moving parts so that long and trouble free service will be rendered. The first ten hours in service are the most important in an engine's life. The "Wasp" engine should render dependable service for long periods of time without disassembly, providing the engine is kept clean, properly adjusted and operated as recommended. It is highly desirable not to disassemble the engine any oftener than is absolutely necessary. Remember that most troubles can be overcome by external adjustment. Do not give the engine a complete overhaul if a "top" overhaul is all that is needed.

To Get the Best Economy.—When cruising at an engine speed of 1,700 r p.m. or less, it is feasible to burn quite a lean mixture and thus effect a saving in fuel. The mixture which gives the best economy at any given throttle setting is somewhat leaner than the mixture which gives the best power. With a propeller which allows the engine to turn 1,900 r.p.m. at full throttle, there is a difference at cruising speeds of about 40 r.p.m. between "best power" and "best economy" for any particular throttle opening. This gives one a ready means of setting the controls to obtain the least possible fuel consumption for any desired speed.

If it is desired to cruise at 1,650 r.p.m., for instance, adjust the throttle

to obtain 1,690 r.p.m. with the mixture control set for the best power or highest revolutions; then lean the mixture down until the speed drops 40 revolutions, or to 1,650, leaving the throttle set as before.

Caution: When flying at full throttle, do not attempt to lean the mixture any more than enough to compensate for altitude. Overheating will result from too lean a mixture at full throttle. At speeds between 1,850 and 1,700 r.p.m. it is all right to run somewhat leaner; the mixture control lever may be set just on the lean side of the position for best revolutions. At 1,700 or below, it is generally possible to adjust for the best economy, always remembering to richen up the mixture before doing any maneuvering. Care should be taken whenever descending to a lower altitude to readjust the mixture control. In general upon ascending the mixture should be leaned out while it must be richened as the plane descends. In gliding in for a landing put the mixture control in the full rich position.

Cold Weather Operation.—Special equipment and operating methods are necessary for satisfactory cold weather operation. Adjustable nose cowling and the hot spot mixture heater are necessary. The oil tank should be inside the cowling, and in cold weather protected from the slipstream In severe climates the oil sump which hangs between the two bottom cylinders of the engine should be lagged with insulating material or shielded. The tank and sump must both have large drains, accessibly located. Some of the early "Wasps" were not provided with sump drains, and for these the makers can supply a sump outlet pipe with a drain plug. All oil should be drained from both the tank and sump immediately before the next flight. A lighter engine oil should be used than for warm weather.

To insure correct readings on the engine oil pressure gauge, it is well to disconnect the gauge pipe at both ends and blow it out clean, and then fill it with castor oil and re-assemble it. The castor oil will not congeal, and a pressure reading will be obtained as soon as the engine pump begins to function. The engine is fitted with primer nozzles on cylinders 1, 2, and 9, and these must be connected to the primer pump furnished. It may be desirable to feed the primer pump from a small separate tank which can be filled with a 50-50 mixture of ether and high-test gas.

Starting.—Check over the engine while still in the hangar. Prepare for starting as instructed above, being sure to shut the adjustable nose cowling, and have the full heat supply turned on to the mixture heater over the carburetor. Fill the tank with hot oil and pull the prop over two or three times by hand. Then roll the ship outside and wind up the starter to the maximum speed. Experience will tell how much priming is necessary, possibly five or six strokes. After starting idle at about 800 r.p.m. until the oil temperature reaches 30 degrees Centigrade or 85 degrees Fahrenheit. Watch the oil pressure and stop immediately if it is not at least 30 pounds. Warm up gradually, opening the throttle as the oil temperature comes up. When the oil temperature reaches 50 degrees Centigrade, or 120 degrees Fahrenheit and the oil pressure is steady at 75 pounds, the engine is ready for flight. When in flight adjust the nose cowling to maintain the oil temperature between 50 and 65 degrees Centigrade or 120 to 150 degrees Fahrenheit. Unless the plane is kept in a hangar at a temperature of 50 degrees Fahrenheit or more, drain the oil from the tank and

sump after each flight.

Periodic Inspection.—After every ten hours flying the engine should be given an external inspection for loose nuts and oil connections, and oil leaks. The carburetor filter and engine oil filter should be cleaned. The sparkplug insulation should be wiped off as dirt or soot on the outside of the plugs can cause short circuiting.

After every 25 hours of flying the valve rocker axles should be lubricated with heavy cylinder oil (not grease) by means of the Alemite gun. This applies also to the valve adjusting screws, which are reached by removing the rocker covers. **Caution: Do not push the valve off its seat with the grease gun as the push rod ball end may come out of its socket. Note: Do not force the adjusting screw ball out of its socket by forcing in too much oil.** The upper ends of the push rods are automatically oiled from the valve rocker axle nipples. In order to insure proper lubrication of the push rod balls which rest in the tappets or cam followers, it is well to remove the push rods and dip them in grease such as "NO-ox-id E" and re-assemble in exactly the same positions as before. Do not use anything but a high grade acid-free nonfluid oil for the above parts; ordinary yellow or Albany grease contains soap or other fillers, and is not suitable. The only other parts of the engine not automatically lubricated are the two magnetos. These should be lubricated with a good grade of medium bodied machine oil every 25 hours of flying. Put about 40 drops in the front oiler and ten drops in the rear one.

The magneto breaker points should be set with an opening of .012 inch. The points must be kept clean and free from oil. Keep the breaker housing clean and free of excess oil. The felt wick should be kept saturated with oil at all times. Oil the carburetor throttle shaft bearings.

The proper valve clearance when cold is .010 inch for both the inlet and exhaust. This is measured between the valve stem and the half ball which pushes the valve open. It is necessary to lift up the rocker arm against the pressure of a light spring before the clearance gauge can be inserted. In checking valve clearances the engine should be turned well past the point where the valve closes; otherwise a false indication of clearance may be had. A box wrench for the valve adjustment lock nut and a valve clearance gauge are found in the tool kit furnished with each engine, as well as a tool for turning the adjusting screw. Do not try to check the valve timing with the running clearance of .010 inch. A special adjustment of the valve clearance must be made before the engine can be timed. (See instructions under "Timing the Engine.") While the covers are off for the purpose of checking clearance it is well to look at the valve springs to make sure none are broken. A valve spring can be replaced without removing its rocker arm. Depressing the valve with the tool provided allows one to take off the push rod enclosure and push rod. The rocker arm can then be tipped up out of the way so there is room to take out the valve spring.

Storage.—When the engine is to be taken out of service and put in storage, all dirty oil should be drained out. About one pint of clean engine oil should be put in each cylinder and the crankshaft turned around several revolutions to make sure that the cylinder walls are well covered. Sparkplug holes should be closed either with plugs or corks, and the exterior of

the engine cleaned. Oil the valve rockers, the carburetor throttle shaft and the magneto, and also oil all external bright metal parts. If tetraethyl lead has been used in the fuel, work oil into all valve stem guides and grease the valve springs thoroughly to prevent rusting.

Top Overhaul.—A top overhaul should not ordinarily be necessary until it is time for a complete overhauling of the engine. Before commencing such work the engine should be checked to see that such an overhaul is really required. The usual indication that an engine needs adjustment or possibly a top overhaul is the reduction in engine speed on the ground with full throttle. It should be borne in mind, in this connection, that extremes in temperature or barometer due either to atmospheric condition or altitude will affect the propeller speed sometimes as much as 50 to 100 r.p.m. and must be allowed for.

First check the mixture control to make sure that the lever on the carburetor is in the full rich position when the control lever in the cockpit is in the corresponding location. Next, check the spark advance at the magnetos in the same manner. At the same time check the magneto breakers with the feeler gauge furnished for this purpose. The gap should be .012 inch. The points should be smooth and free from oil. Clean the strainers in the fuel supply line, and be sure that fuel reaches the carburetor in adequate quantities. The best way to determine this is to disconnect the pipe at the carburetor, and open the fuel valves, observing whether the pipe runs full of fuel or not. The valve and magneto timing should be checked in accordance with the instructions contained in the section on "Complete Overhauling." While this is being done, examine the valve springs for breakage.

After the above checking has been done, and adjustments made, if necessary, start the engine and warm it up at low speed (800 to 1,000 r.p.m.) until the temperature of the entering oil is at least 100 degrees Fahrenheit or 40 degrees Centigrade. Next, try the engine at full throttle with the mixture control set full rich, and the spark full advanced. Observe the revolutions per minute, oil pressure, which should be between 75 and 100, and fuel pressure, which should be between three and four pounds. Next, check the operation of the ignition by running first on one magneto and then on the other. If the ignition is found satisfactory and fuel pressure is three or four pounds, and the engine still does not turn up to the required ground speed, it is probable that a top overhaul is necessary. One other check, however, is suggested; after the engine has been stopped by running the fuel out; and allowed to cool down for five minutes, the compression should be tried in the various cylinders. It will be necessary to turn the engine over two complete revolutions in order to test the compression in all nine cylinders. If this is found to be good, it is not likely that a top overhaul is needed and there is probably some other reason for the loss in revolutions.

Disassembly.—Tools for making ordinary adjustments and minor repairs are found in the canvas tool roll furnished with each engine. A list of these follows and includes the following special tools: Valve Spring Compressor, Spanner for Inlet Pipe Nut, Cylinder Nut Wrench, Box Wrench

for Valve Adjustment Lock Nut, Valve Clearance Gauge. When only a top overhaul is required, it can be readily accomplished while the engine is installed in the airplane All tools are given a special number in the list and are referred to in the text by that number.

WASP SERVICE TOOL KIT

Alemite-Zerk Oil Gun ..	PWA— 14	Valve Adjusting Screw Tool ...	PWA--140
Carburetor Jet Wrench	PWA— 45	Wrench—7/16" and 1/2" openings	PWA-- 21
Cold Chisel—6" . .	PWA -- 32	Wrench—9/16" and 3/4" openings.	PWA-- 22
File, Half-round . ..	PWA— 38	Wrench, Crescent 6" Adjustable.	PWA-- 20
File Pillar . .	PWA-— 39	Wrench, Cylinder Stud Nut, and Handle	PWA -- 25
File, 3 sided	PWA-- 40	Wrench, Intake Pipe Nut . .	PWA--144
File, Magneto	PWA— 41	Wrench, Magneto Adjusting	PWA-- 23
Gauge, Valve Clearance .	PWA— 35	Wrench, Monkey . . .	PWA-- 19
Hammer	PWA- 34	Wrench, Oil Strainer and Relief Valve	PWA-- 24
Pliers, Combinations ...	PWA— 31	Wrench, Stillson	PWA-- 42
Pliers, thin nose ...	PWA – 43	Wrench, Valve Adjusting Lock Nut	PWA-- 28
Punch, Drift ..	PWA- 33	Wrench Handle, Sparkplug . .	PWA--123
Screwdriver—4" .	PWA— 30	Wrench Socket, Sparkplug . ..	PWA 124
Screwdriver- 8" . .	PWA— 29		
Tool Roll, Canvas	PWA— 36		
Valve Spring, Compressor	PWA— 15		

First place the airplane in a clean protected spot Dust and dirt wear out more engines than anything else. Then remove the cowling surrounding the engine. Next, the engine should be thoroughly washed off with gasoline before attempting any disassembly work. With the engine thus prepared and some tins or boxes provided for the parts to be removed, the cylinder hats should be taken off. The push rod enclosures are removed by telescoping the tubes and locking them by means of a slight twist, after which the valve springs should be compressed by means of the tool provided in the tool kit as shown at Fig. 629 A. This will permit the removal of the push rods and enclosures. In this operation care should be taken that the valves are closed before trying to compress the springs. Although the push rods are marked at the tappet end to correspond with the cylinder numbers, it is best to lay them out in the order in which they are removed from the engine. It is highly desirable that they be replaced in the exact position from which they came, as the ball ends have been worn to a perfect seat.

With the push rods removed, the next operation is to take off the inlet pipes. In doing this the spanner wrench provided should be used for loosening the packing at the bottom of each pipe before removing it. The packing nut should not be entirely unscrewed. Care should be taken in handling these intake pipes as they are light wall tubing and readily dented. Take off the oil sump which is between the two bottom cylinders. There are two oil pipes which connect to the top of this casting. The rear one stays in the engine and the front one comes off with the sump. It is necessary to carefully pull the sump straight down in order to keep from bending these two pipes.

No. 1 cylinder should always be removed last and installed first. This cylinder positions the master rod. A special wrench will be found in the

tool kit to remove the cylinder stud nuts, after which the cylinder can be readily removed. In doing this, however, care should be taken not to allow the piston to drop and thereby become nicked. Care should also be taken not to mar the bottoms of the cylinder barrels. These should be carefully set down on wood in order not to distort or burr the end of the barrel. Each piston must be brought up to the top of its stroke before its cylinder is removed. If this is not done, the scraper ring is likely to be broken in attempting to get it out of the crankcase.

As soon as any one cylinder has been taken off, the piston should be removed by pushing out the wristpin. If this cannot be readily done, the head or top of the piston should be slightly heated by means of a blow torch, and the pin tapped out by using a fiber drift shaped to fit the wristpin plug. Care must be taken not to drive these pins with any considerable force. The application of more heat will expand the piston sufficiently to enable the pins to be removed with ease.

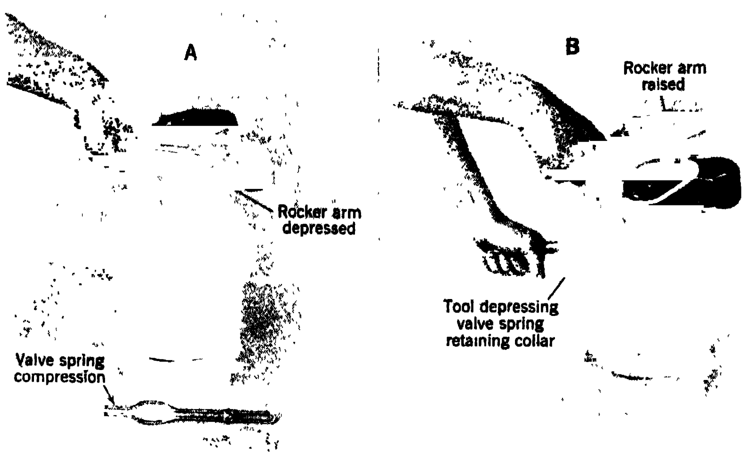


Fig. 629.—Use of Valve Spring Compressor to Depress Rocker Arm for Removing and Replacing Push Rods Shown at A. B Shows How Compressor is Used to Remove Valve Spring Collar.

Inspection of Connecting Rods.—With the cylinders removed, an inspection should be made of the master connecting rod and link rods. By moving each one, both up and down and sideways on the crankpin, a rough check can be made of the clearances. If these parts are in good condition, very little play will found in the master rod, except sideways on the pin The link rods, however, will feel somewhat loose, as they have normally .002 inch clearance on the diameter of the pin, and .006 inch to .008 inch sideways. It is advisable to try the wristpins in their respective rods. It should not be possible to insert more than a .002 inch feeler between the pin and the bushing. If more than .003 inch clearance is found, it is desirable to replace the bushing. Unless the engine is particularly dirty, it is

not advisable to wash the rods and shafts with gasoline, as it is rather difficult to re-oil them satisfactorily. Consequently, after the inspection, a large clean piece of cloth or paper should be tied around the entire crankcase while the cylinders are being overhauled to make sure no foreign matter will find its way into the crankcase.

Removing Valves.—To facilitate the handling of the valves, a block of wood should be secured between five inches and 5½ inches in diameter and eleven inches long, and rounded at the upper end to fit the cylinder dome. Care should be taken that this wood is kept clean, as chips or dirt will readily mar the cylinder barrels. By placing the cylinder over this block, the valves will be held shut and it will be easy to remove the valve springs by using the tool provided, in the manner shown at Fig. 629 B. It is not necessary nor desirable to remove the rocker arms to take out the valve springs. As soon as the spring has been depressed, the split cone can be removed and the valve washers and valve springs taken out. After this is done, the locking wire should be removed; this will be found snapped into a groove near the outer end of the stem. Next, be sure that there is no burr on the valve stem, particularly at the edge of the lock wire groove. In case there is, it should be removed with a fine file before attempting to remove the valves.

An examination should be made of the valve stems and their clearance in the valve guides before any regrinding is attempted. Care should be taken not to use emery cloth on the valve stems unless absolutely necessary since it removes the glaze resulting from continued operation of the engine. The guide clearance can be checked by means of plug gauges furnished in the station tool equipment. If the clearance is excessive, the valve guide should be replaced. See the instructions contained in the section on "Complete Overhaul."

Valve Grinding.—Before attempting to regrind the valves, any excessive carbon should be removed from the cylinder heads, great care being taken not to mar the valve seats during the operation. The carbon should also be removed from the cylinder side of the valves. The valves should be carefully handled in order to avoid scratching or burring the seats. Valve grinding tools are provided for holding the inlet and exhaust valves while grinding. The grinding compound should be kept away from valve guides and cylinder bores and all traces of it should be washed away after the grinding operation is finished.

As a rule, it should not be necessary to re-cut the valves or seats, lapping with grind compound being sufficient to put both the valves and seats in good condition. After the valve grinding has been completed, the parts should be very thoroughly cleaned before re-assembling and the valve stems oiled, as well as the rocker balls, push rod balls and rocker arm bearings. Be sure to replace the safety snap rings on all valve stems as soon as the valves have been put into their guides.

In replacing any valve springs which may be broken or rusted, use the same type as those removed. On engines on which the lift of the inlet and exhaust valves is the same, the combined inner and outer valve springs should require 140 pounds to compress them to a length of 1$\frac{7}{16}$ inch; on engines on which the lift of the inlet valve is ⅛ inch greater than that of

the exhaust, the spring pressure is 102 pounds at the same length.

Inspection of the Pistons.—The piston rings should bear around their circumference, and preferably have no more than .025 inch end clearance when the ring is in the cylinder. Moreover, they should be entirely free in the ring grooves. If it is necessary to replace rings which do not meet these requirements, it is desirable to put the new rings in the lower grooves. In this way the old rings which fit the cylinders will provide proper protection for the new rings until they are run in. For further instructions on fitting piston rings, see the section on "Complete Overhaul." New oil rings should be used if the scraping surface is more than half the width of the ring. The wristpin should be a push fit in the piston at room temperature, or 70 degrees Fahrenheit. If it is too tight, the piston should be carefully reamed to provide the proper fit using the reamer in the station tool equipment. It should be noted that in cold weather, due to the contraction of the aluminum, the pin will be tighter than normal. Before re-assembling the cylinders on the crankcase, an examination should be made of the cylinder pads on the crankcase and all burrs, etc., should be removed; these might cause oil leaks.

Assembling.—To re-assemble the engine, replace the No. 1 piston on the master rod with piston number facing the propeller. Carefully space the piston rings so that the slots on the compression rings are 120 degrees apart; in other words, so they are spaced equally around the piston. See that the oil scraper ring is in place, with the scraping edge toward the bottom. Next, carefully oil the piston with clean engine oil, and wipe out the cylinder barrel and oil it. After this is done, compress the piston rings by means of the ring clamp provided in the station kit, and put on No. 1 cylinder which should be carefully and completely fastened down before attempting to install the next cylinder. The hold-down nuts should be tightened down evenly all around with a wrench provided and safety wired. Repeat the above process for the installation of the other eight cylinders, and then replace the push rods in their enclosing tubes, being careful to put them back in the same position as they formerly had. Moreover, be sure that the gaskets at both ends of the enclosure tubes are in good condition and in proper position. Next, attach the intake pipes, being careful that the packing end of the pipe is round and smooth. The three-cornered intake gasket on the cylinder should be in good condition. If not, replace it. Do not tighten down on the packing nuts with anything but the spanner wrench provided in the tool kit, and note that these nuts should not be tightened up too tight, or damage will be done to the intake pipes.

With the cylinders, push rods, and intake pipes in place, set the valve clearance to .010 inch, using the box wrench provided. It is essential to turn the engine half a revolution from the intake closing before attempting to set the tappet clearance for any particular cylinder. This will insure that the valves are on their seats. As there is a spring in each tappet which keeps the push rod engaged with the rocker arm, it is necessary to lift the rocker arm in order to insert the clearance gauge. It is not necessary to re-time the engine after a top overhaul, as the cam mechanism is not disturbed

Before replacing the oil sump, remove the screen and clean it. Be careful that the front pipe is in place in the sump and the rear pipe in the blower

section, and that both are round and smooth. Do not force the sump up into place. The suction pipe which takes oil from the bottom of the sump must have a good gasket and must be bolted up tight.

Before attempting to start the engine, the routine inspection referred to in the section of this chapter on "Periodic Inspection" should be conducted.

Running In.—It is desirable to operate an engine which has been given a top overhaul for two to three hours, starting slowly and gradually increasing speed before attempting to run the engine at full throttle or fly the plane. This running should be done before replacing the engine cowling. Afterwards a check should be made for oil leaks and the tightness of all connections, etc. If a whole new set of rings has been used on any one piston, or other new parts installed, it is desirable to run the engine at least two hours more, and it is preferable to operate it with the least possible amount of full throttle running for five or ten hours thereafter, in order that the new parts may be properly run in and seasoned. If the engine turns up to its customary ground speed, and the oil pressure is between 75 and 100 pounds at full throttle, the engine can be considered in good shape and ready for further service. After running in, the valve clearance should be re-checked, as the valves may have bedded in somewhat. The engine must be cold when the clearance is checked, or a false indication will be given.

Complete Overhauling.—A complete overhaul should not be required before 300 to 400 hours service. However, unusual indications such as excessive oil consumption or the finding of metal particles in the sump strainer may show the need for examination. Whenever it is necessary to make a complete overhaul, it is preferable to remove the engine from the ship and carry out the work on an engine assembly stand. On the other hand, if it is only necessary to examine the master rod or crankshaft, the blower and rear sections may remain in the plane while the nose and main section of the case are removed as a unit. This may be accomplished by first removing the propeller, the intake pipes and oil sump, and then separating the engine between the blower and the rear section of the main case. Be sure to block the wheels of the plane first and support the engine by the lifting hooks.

The "Station Tool Equipment" listed below contains all the special tools necessary for completely overhauling the engine. In the following pages "front" refers to the propeller end of the engine, "right" means the right side looking at the rear of the engine. No. 1 cylinder is the top cylinder and carries the master connecting rod. The cylinders are numbered in order 1, 2, 3, etc., counting in the direction of rotation of the engine; that is anti-clockwise as viewed from the propeller. The firing order is 1-3-5-7-9-2-4-6-8. **Caution: Always use a fiber drift whenever it is necessary to separate or drive parts together. Considerable damage may otherwise result.**

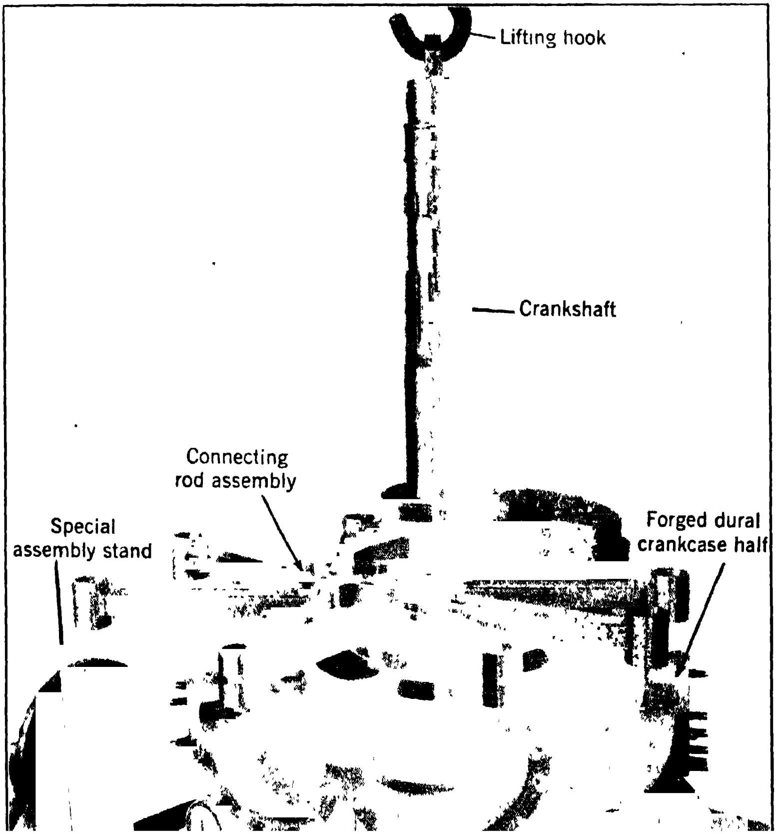
Complete Overhaul.—Before removing the engine from the ship, the propeller hub should be removed by pulling the locking cotter and unscrewing the propeller hub nut. A steel bar ⅞ inch in diameter and about three feet long should be used for this purpose. To lift the engine, use a sling

attached to the lifting eyes behind cylinder No. 1. The engine will balance perfectly when supported at this point. A spreader should be used to protect the No. 1. cylinder. After the engine has been removed from the ship, it should be placed on the assembly stand and thoroughly cleaned with gasoline before any other work is undertaken. A clean protected work shop is essential for a complete overhaul. Clean pans or boxes should be

REPAIR STATION TOOL EQUIPMENT

	"Hornet"	*"Wasp"*
Blower Gear Holder	PWA—48	PWA—48
Cabinet, Station Tool		PWA—132
Cam Gear Holder	PWA—121	PWA—100
Clamp, Piston Ring	PWA—49	PWA—13
Drift, Exhaust Valve Guide	PWA—120	PWA—94
Drift, Inlet Valve Guide	PWA—95	PWA—95
Drift, Piston Pin	PWA—12	PWA—12
Lifting Eye, Crankshaft	PWA—111	PWA—91
Lifting Sling	PWA—37	PWA—37
Plug Gauge, Exhaust Valve Guide	1323—T 3	1516—T- 10
Plug Gauge, Inlet Valve Guide	1516—T—11	1516—T—11
Puller, Blower Impeller	PWA—51	PWA—51
Puller, Crankshaft Assembling	PWA—101	PWA—92
Puller, Crankshaft Bearing	PWA—69	PWA—69
Puller, Crankshaft Disassembling	PWA—105	PWA—82
Puller, Exhaust Valve Guide	PWA—119	PWA—87
Puller, Inlet Valve Guide	PWA—86	PWA—86
Puller, Knuckle Pin	PWA—118	PWA—84
Puller, Magneto Gear	PWA—70	PWA—70
Puller, Nose Section	PWA—67	PWA—67
Puller Valve Rocker Axle	PWA—72	PWA—72
Puller, Valve Rocker Bearing	PWA—73	PWA—73
Reamer, Exhaust Valve Guide	PWA—116	PWA—8
Reamer, Inlet Valve Guide	PWA—8	PWA—9
Timing Pointer	PWA—115	PWA—85
Timing Wrench	PWB—44	PWB—16
Valve Grinding Tool, Exhaust	PWA—117	PWA—11
Valve Grinding Tool, Inlet	PWA—10	PWA—10
Valve Seating Tool	PWB—6	PWB—6
Wrench, Blower Impeller Nut	PWA—50	PWA—50
Wrench, Blower to Crankcase	PWA—52	PWA—52
Wrench, Blower Gear (Ratio 10 1 7·1)	PWA—151	PWA—151
Wrench, Crankshaft Bolt	PWA—106	PWA—93
Wrench, Crankshaft Plug and Cam Gear	PWA—7	PWA—7
Wrench, Crankcase Main Bolt	PWA—145	PWA—145
Wrench, Crankcase Main Bolt Nut and Special Nut A—561	PWA—142	PWA—142
Wrench, Thrust Bearing Nut	PWA—114	PWA—3
Wrench, Rocker Arm Adj. Screw Nut	PWA—53	PWA—53
Wrench, Supercharger Drive Gear	PWA—109	PWA—109
Wrench, Timing Adjusting and Bushing		PWA—146
Additional Tools, not regularly furnished.		
Assembling Stand for Engine	TAM—2	TAM—2
Reamer, Knuckle Pin Bushing	PWA—128	PWA—90
Reamer, Knuckle Pin Bushing	PWA—130	1010—T—2[illegible]
Reamer, Master Rod Bearing (Old)	PWA—110	PWA—46
Reamer, Master Rod Bearing (New)		147
Reamer, Piston Pin Bushing	PWA—129	PWA—89
Reamer, Piston Pin Bushing	PWA—131	1010—T—2[illegible]

provided for the parts. Next, remove the cylinders and pistons in accordance with the instructions contained in the section entitled "Top Overhaul." For this work the crankshaft should be vertical. Unscrew the thrust bearing nut, No. 1,019, by means of the special wrench provided in the service kit, and remove the thrust cover. Next, remove the twenty nuts which fasten the front section to the main section of the crankcase. It will then be possible to remove the nose section, together with the thrust bearing which is carried in it, by using the puller which fits over the end of the



ig. 630.—Method of Removing "Wasp" Engine Crankshaft and Connecting Rod Group from the Crankcase.

crankshaft and fastens onto the studs in the front of the nose section. Do not drive on the valve tappet guides when trying to remove the nose section nor pry underneath the flange connecting it with the main case with screw drivers.

After the nose has been removed, it will be possible to slide off the timing sleeve, No. 1,534, and take out the crankshaft key. If the sleeve does not come off readily, it may tapped off by means of a fiber drift and hammer. As soon as this has been removed examine the shaft for burrs and remove them before endeavoring to slide the cam off the shaft. With the cam removed, the oil distributor bracket will be exposed. This may be taken off by undoing the six nuts. Care must be taken to unfasten the oil pipe bracket, which acts as an additional fastener for the distributor casting.

Taking Down Crankcase.—The main crankcase may now be split by removing the nuts from the nine through bolts between the cylinders and gently tapping the bolts back as far as they will go. Do not drive these bolts against the blower section. The forward section of the main case may now be lifted off the shaft. It will probably be necessary to tap on two opposite sides of the case with a fiber drift and hammer while the case is being lifted. Take pains to draw the case off straight so as not to cramp the bearing. The crankshaft may now be removed, preferably by screwing the lifting eye into the forward end of the shaft and lifting the whole assembly by means of a hoist as shown at Fig. 630. The same lifting eye may also be used, if it is necessary to lift the complete engine with the shaft in a vertical position. The next operation is to remove the nuts which attach the main case to the blower section and take off the main case.

Disassembly of Accessory Section.—The accessory section should never be disassembled unless it contains some known defect. All the gears may be examined by removal of the fuel and oil pumps after the main case has been dismantled. The supercharger impeller may be inspected by removing the four screw plate on the intake elbow above the carburetor. If a complete disassembly is necessary, turn the assembly stand so the accessories are in their normal position, then remove the magnetos, starter and carburetor and take off the magneto drive bearing covers. Next remove the three drive shafts as follows:

The starter jaw is held on by a nut at the rear end. Remove this nut and tap the shaft out toward the front. Each magneto shaft coupling is held on by a cap screw in the rear of the shaft. Removal of the coupling and taking out the key allows the shaft to be pushed out forward. Removal of the fuel and oil pumps with their bevel gears will permit the magneto shaft bevel gears to be taken out. The gun synchronizer couplings are screwed on their shafts and held by straight pins covered with spring steel snap rings. These shafts are taken out through the pump openings. With the shafts out, turn the rear section uppermost and it may then be unbolted from the blower and these two parts separated by tapping with a soft hammer. Do not pry apart with screwdrivers. Care must be taken to draw the rear section straight up because the three accessory shaft bushings which are pressed into the rear section also fit in the blower section. When setting the rear section down, avoid resting it on the projecting oil pipe.

The Wasp engine can be fitted with blower gearing of different ratios, according to the purpose for which the engine is used. The earlier engines have 5:1 ratio nonfloating gears. All engines rated at 450 horsepower have 7:1 ratio gears with a floating drive gear. In handling the 5:1 non-floating gears, proceed as follows: To disassemble the blower gearing take out the impeller nut pin and unscrew the nut with the fish tail screwdriver. This nut has a left hand thread. Use the special tool provided for holding the gears as shown at Fig. 631. Do not insert a screwdriver between the teeth for this purpose. Take off the impeller, using the special puller. The aluminum cover over the blower shaft bearing may now be removed.

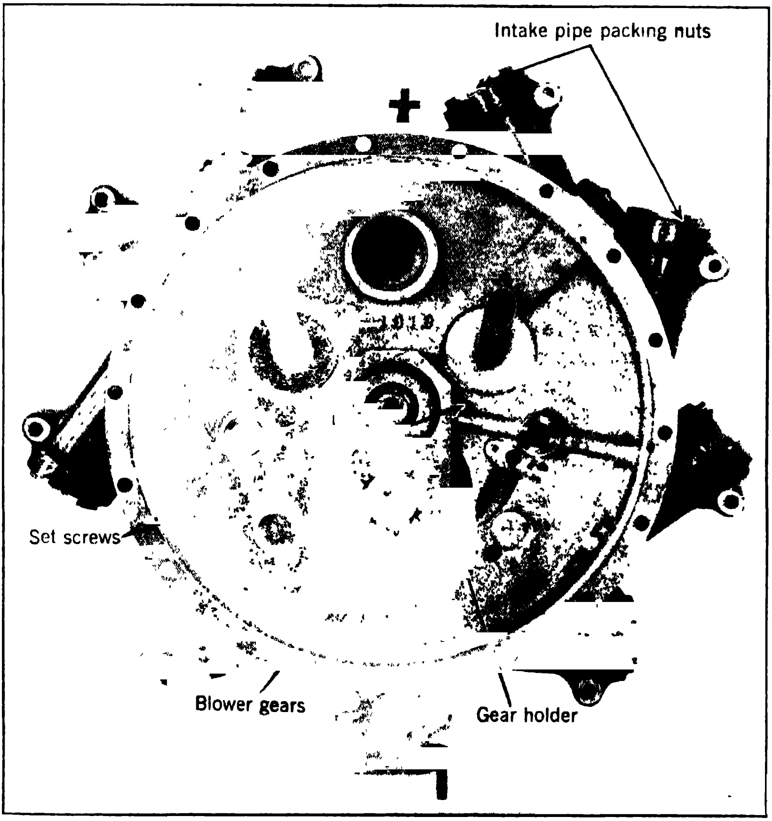


Fig. 631.—"Wasp" Engine Blower Gear Holder in Use to Hold Blower Gears Stationary While Impeller Nut and Bearing Retaining Nuts are Applied or Removed.

The blower intermediate shaft rear nut should be taken off, followed by the front nut on the same shaft. The blower gear holder is used during this operation, as well as when removing the blower nut. The double gear is now free and can be taken out, after which the intermediate shaft may be withdrawn. Removing the front nut from the blower impeller shaft allows this shaft to be taken out towards the rear, together with one

of its bearings. In order to remove the other bearing it is necessary to take out the bearing cage. To do this, press out the cage with an arbor shaped to fit it. If the cage is excessively tight, apply a gentle heat to the boss. When replacing the cage, the slot in its rear edge must be lined up with the slot in the blower section. **Caution: Excessive heat will spoil the bearing.**

Floating Gears.—In the floating gear assembly, the crankshaft gear does not comprise two spur gears as in the solid drive, but has a single gear which takes care of the starter and magneto drives. On the inside of this gear are clutch teeth which engage the blower driving gear. The driving gear is independent of the crankshaft and floats on its own bronze bearing, supported by the blower section of the crankcase. Removing the six screws on the face of the bearing will allow the bearing and gear to be withdrawn.

To remove the nuts on the impeller shaft and the intermediate shaft, fix the gears in position with the "Blower gear holder" shown at Fig. 631 which has internal teeth to slip over the intermediate pinion. If the intermediate shaft should turn in its gear, it may be held by means of the slot in one end. The intermediate shaft has to be driven out of the double gear (forward) before the gear can be taken out of the case. The gears and bearing should not show excessive wear. The impeller should be a good fit on the splined shaft. Make sure the oil drain holes and grooves are open. Test the passage which supplied oil to the blower gears and especially the oil feed to the floating gear bearing.

The oil strainer and oil pressure relief valve should be taken out and all oil passages in the rear section thoroughly cleaned. The sump strainer should be removed and the sump cleaned out, as well as the pressure oil pipe which passes through the sump. Disassemble the oil pump and see whether excessive wear calls for replacement of any parts.

Disassembling Crankshaft.—This engine has a one-piece master rod and a two-piece crankshaft. To remove the master rod the crankshaft is best held while working on it by grasping the front counterweight in a soft-jawed vise, as shown at Fig. 632 A. The accessory drive gear should then be removed from the rear end of the shaft by unscrewing four cap screws found inside the gear. The rear roller bearing may then be taken off, using the puller provided, as shown at Fig. 632 B. The crankshaft is fastened together with a through bolt secured by a cotter pin located near the head. Take out the cotter pin and unscrew the bolt using the special box wrench. It will be noticed that there are two separate threaded portions of the crankpin. After the bolt is unscrewed a certain distance, it will be free in the crankpin but cannot be removed until it is screwed back through the second thread.

Two special screws are provided for use in separating the two parts of the shaft. The smaller of these is designed so it can be screwed into the forward end of the crankpin without requiring the removal of the front main bearing. Screw this piece in until all its threads are engaged, but no further. Now insert the larger screw in the opposite (rear) end of the crankpin after oiling it thoroughly. Screwing up this large screw will force the shaft apart. Be careful to avoid dropping the rear section when the shaft comes apart.

Rod Disassembly.—Remove the rod assembly and place on a clean cloth or paper for examination. If the master rod bearing is in good condition, and the link rods have the required clearance, it is strongly recommended that the assembly be not disturbed, except for thoroughly washing. Should it be necessary to remove the link rods, first remove the four locking plates. When these plates have been taken off, the knuckle pins may be pulled out one at a time by using the knuckle pin puller furnished.

Miscellaneous Disassembly.—Valve springs can be taken off without removing the valve rockers. The rocker arms should not be disassembled unless absolutely necessary. For the removal of the rocker arms two pullers are furnished, one for removing the bearing and one for pulling the pin out of the valve rocker. Section A-A of the engine assembly drawing at Fig. 621 shows the construction of the rocker shaft. Remove the central bolt and apply the bearing puller on the side nearest the shoulder of the pin (the right hand side in the sectional drawing). Pull the rocker and bearings over until the rocker touches the housing. Removing the puller will expose one bearing, which should be taken off. Now use the other puller to remove the pin from the rocker.

Each tappet has an internal spring which acts to raise it off the cam. In order to remove a tappet it is necessary to push it in as far as it will go and take out the roller pin and roller. The tappet and guide can then be removed. To take the tappet out of the guide it is necessary to remove the pin which holds the tappet spring. It should not be necessary to remove the tappets from the front section unless excessive wear is evidenced.

The intermediate cam gears, part Nos. 1,009 and 1,548, should be removed from the front main crankcase so the bushing can be examined for wear. The retaining nut is secured by a cotter pin inside the gear hub, and a special wrench, No. PWA-7, is used for this nut, while the gear is held by PWA-100. Blow out the oil passage in the crankcase to make sure it is clear.

Clutch for Blower Drive.—The high rotative speed of the blower impeller gives it considerable flywheel effect in spite of its light weight. To absorb any shocks due to sudden changes of speed, a slipping clutch is provided between the crankshaft and the floating gear which drives the blower. The clutch is assembled inside the crankshaft gear as shown at Fig. 633 and comprises: 2,144, a steel plate to provide a wearing surface; 2,208, a toothed bronze piece piloted in the crankshaft gear, forming the driven member of the clutch, and which drives the floating blower gear by its teeth; 2,203, a thin steel plate keyed to the driving member; 2,204, a thin bronze plate keyed to the toothed piece; 2,207, a steel plate which presses the other plates together and which is keyed to the crankshaft and has a pilot in the central hole of the crankshaft. A spring, 2,120, exerts pressure on 2,207, and is anchored by a bolt, 2,143, screwed into the rear crankshaft from the front side.

To disassemble the clutch, undo the small nut at the rear and remove the spring. The plates will stick together on account of the oil on them. The puller PWA-153 should be screwed into part 5 which can be taken out by a direct pull or by screwing the puller all the way in until it hits a shoulder on the central bolt and jacks the plate out.

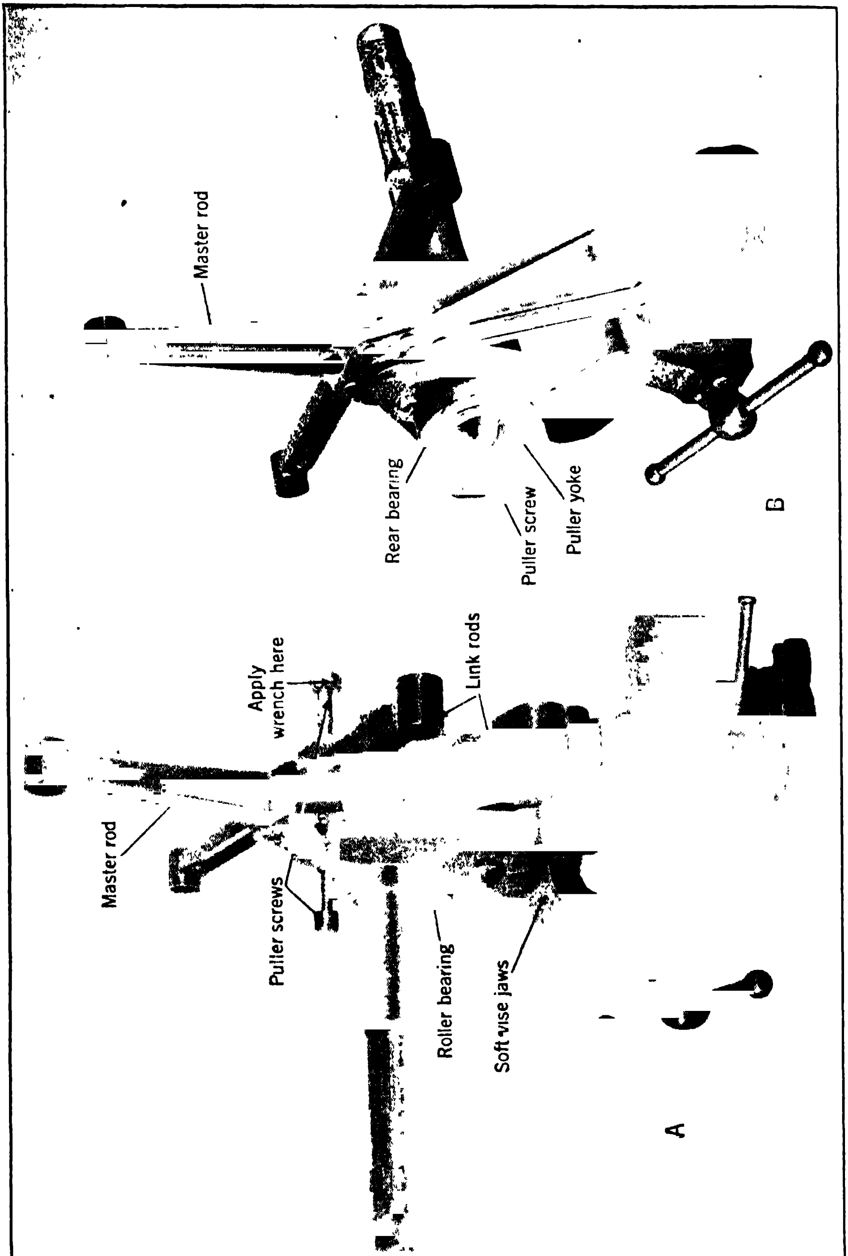


Fig. 632.—A Shows Method of Holding "Wasp" Crankshaft for Taking Down. B Outlines the Method of Removing the Rear Bearing from the "Wasp" Crankshaft.

An oil jet in the crankshaft (see drawing) lubricates the clutch, and should be checked to see that the passage is clear. The central bolt need not be removed from the shaft. Note, however, that if for any reason this bolt should be replaced, it must be locked in place by punching the flange into a small countersink in the crankshaft. After the clutch parts have been taken out of the crankshaft gear, the latter may be removed by taking out the flat head screws which hold it to the crankshaft. The various parts then appear as shown at Fig. 634.

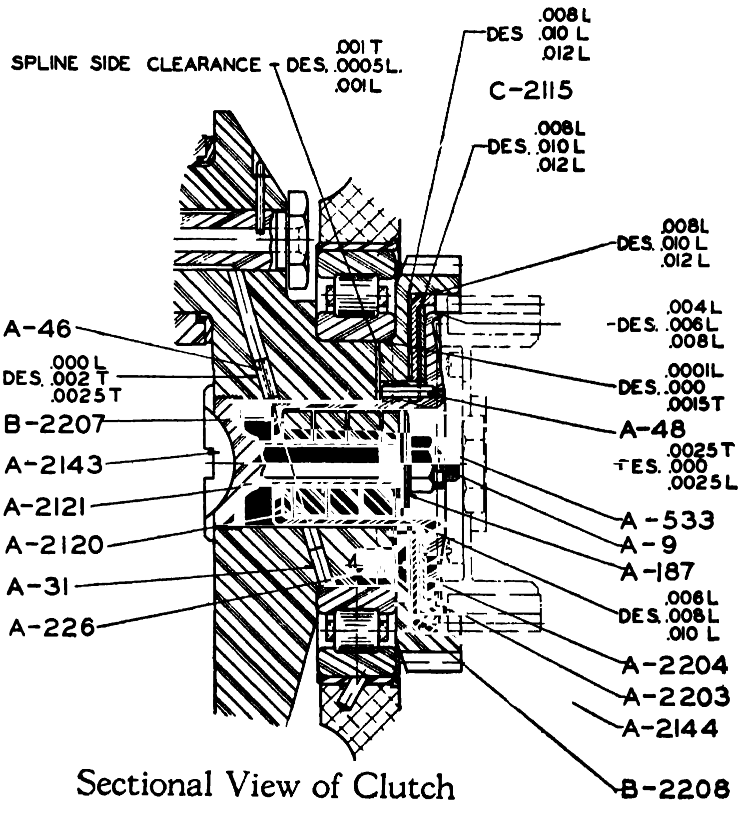


Fig. 633.—Assembly Drawing of "Wasp" Supercharger Drive Clutch.

Assembling Clutch.—The various parts should be inspected to see that the friction surfaces are smooth and that there is no noticeable wear on the keys which prevent turning. The teeth which engage the blower drive gear should be examined. After making any necessary replacements, clean and oil the parts and put them together in the reverse order to disassembly, having first assembled the two halves of the crankshaft and put on the rear bearing and gear. Be sure to put in the spacer that goes inside the spring, and screw the nut up tightly against this spacer. The length of the spacer

determines the spring pressure and hence the holding power of the clutch. Before putting the crankshaft in the engine, however, it is well to check the clutch as follows:

Hold the crankshaft in a soft-jawed vise so that the clutch overhangs the edge of the bench as shown at Fig. 635. To turn the clutch it is necessary to have a gear similar to the floating blower gear, with a lever arm attached to it. (See photo at Fig. 635.) With the arm horizontal, the clutch should sustain a 50 pound weight hung at a distance of 27 inches from the center of the crankshaft; this is a turning moment of 112½ pounds-feet. The clutch should be tight enough so that with the lever slightly above the horizontal and the weight hanging as above, striking the top of the lever with the hand will cause the weight to fall a couple of inches and then stick again. If it is necessary to increase the tension of the clutch spring, take out the spacer which goes inside the spring, and face it off slightly, keeping the ends square. Before testing the clutch it is well to take hold of the lever arm and work it back and forth, to squeeze out surplus oil.

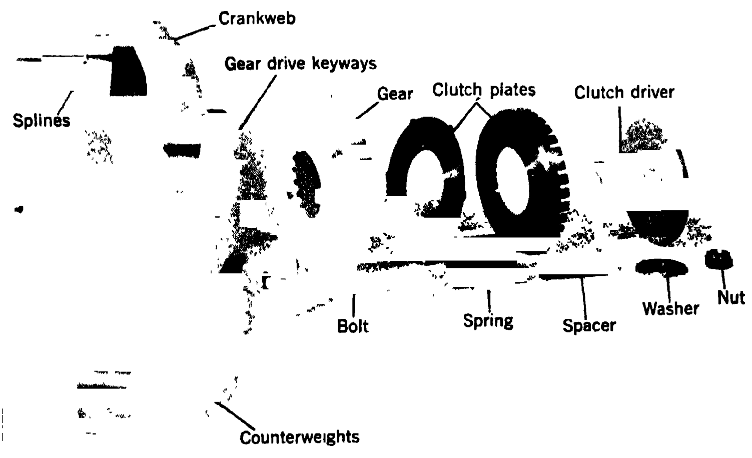


Fig. 634.—Supercharger Drive Clutch of "Wasp" Motor Taken Down to Show Parts.

Inspection.—After disassembly, all parts should be thoroughly cleaned and laid out in groups on a clean bench for inspection. As the parts are examined, make a list of all defects and all parts that are to be replaced.

Connecting Rods.—The link rod bushings should be examined for excessive wear or roughness. The maximum clearance to be allowed is .003 inch on the piston pin bushing and .0025 inch between the knuckle pin and its bushing. The side clearance between the master rod and the link rod should not exceed .010 inch. If excessive wear is shown or if the bushings are scored or scratched, they should be replaced. The surface of the knuckle pins should be smooth. Any slight roughness can be stoned down but deep scratches indicate that the pin should be replaced. Make sure that the oil plugs inside the knuckle pins are tight and without any evidence of leaking.

The maximum clearance between the master rod bearing and the crankpin is .003 inch, and the end clearance of the master rod should not be more than .020 inch. Blow out the oil passages in the master rod.

Crankshaft.—The crankshaft screw oil plugs should be taken out so that the inside of the shaft can be cleaned. Examine both crankshaft main bearings for wear. The cam driving gear and the cam sleeve should be a slip

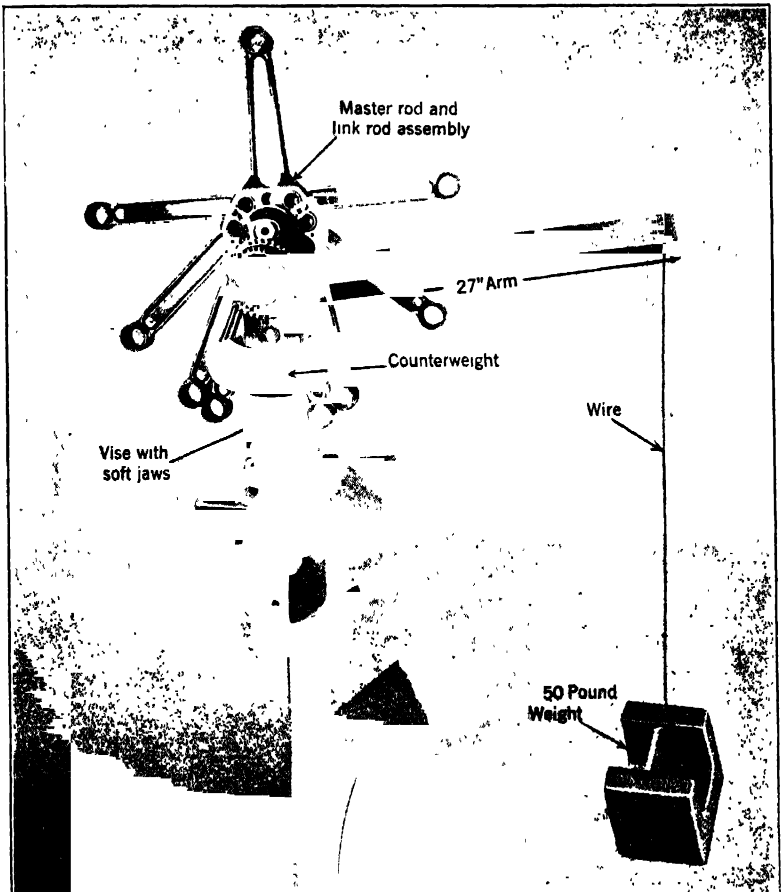


Fig. 635.—Method of Testing Holding Power of "Wasp" Motor Supercharger Drive Clutch.

fit on the crankshaft so that the timing adjustment can be made when the engine is re-assembled. If there is any roughness, smooth up the shaft with a fine stone. A hardened steel washer is used between the two halves of the crankshaft. Any roughness on the face of this washer or on the corresponding part of the crankshaft should be removed with a fine stone.

The cam hub should have a clearance of not over .006 inch on the crankshaft sleeve. The outside of the cam hub runs in the oil distributor bearing.

If the surface at this point has been cut by dirt in the oil, it should be smoothed up. No greater clearance than .010 inch on the diameter should be permitted at this point. Examine the internal gear of the cam for wear. Examine the propeller thrust bearing which goes on the forward part of the crankshaft and if there is any looseness it should be replaced. See the section headed "Clutch" for information on the clutch parts.

Pistons.—The pistons should be carefully cleaned and examined. The wristpin should be a push fit at room temperature, or 70 degrees Fahrenheit. If it is too tight, the piston should be carefully reamed to provide the proper fit with the reamer in the station tool equipment. In this connection, it should be noted that in cold weather, due to the contraction of the aluminum, the pin will be tighter than normal. Examine the wristpin bosses for cracks. The piston rings should bear around their entire circumference and preferably have no more than .025 inch end clearance while in the cylinder. Moreover, they should be entirely free in the ring grooves. A convenient method of checking the end clearance of a ring is to put a piston in the cylinder and then put the ring in place against the end of the piston This will make it easy to insert a feeler in the ring gap and determine the exact clearance. If it is necessary to replace rings which do not meet these requirements, it is desirable to put the new rings in the lower grooves. In this way, the old rings which fit the cylinders will provide proper protection for the new rings until they are run in. New oil rings should be used if the scraping surface is more than half the width of the ring. Be careful not to spread the rings any more than necessary in removing or replacing them. Rings with less than ¼ inch gap when free should be replaced because their tension is too low. Five pounds is the minimum tension that may be satisfactorily used. The ring tension is tested by resting one side of the ring on a platform scale with the slot at one side (90 degrees from the point of contact with the scale) and noting the amount of pressure that must be applied to the top of the ring to close the slot.

Cylinders.—Cylinder barrels should be examined for taper and roundness by the use of an inside micrometer or a special Ames dial indicator. Cylinders tapered or out of round more than .003 inch should be replaced The inner surface, of course, should be smooth. The cylinder barrel and cylinder head are permanently attached to each other and cannot be detached. In case a cylinder is damaged by over priming, running without oil or for other reasons, it is necessary to replace the complete cylinder and head assembly. Inspect the valve guides for wear and look for cracks in the cylinder head casting. A crack may be found after long service across the cooling fin which connects the inlet and exhaust parts. This does no harm.

Gears.—The cam driving gears should be inspected for wear. The gears should be stoned if necessary to remove any roughness. The blower driving gears should be examined carefully. The oil channels in the blower section should be cleaned out. Inspect the both halves of the main crankcase for cracks. Be sure all piping is in good condition. If not, it should be replaced.

Replacement of Parts.—When the inspection has shown that certain parts need renewing, all necessary replacements should be made before

beginning to assemble the engine. Be sure to fit the parts to the clearances shown at Figs. 621 and 622. This is absolutely essential for proper operation. Number each new part to correspond to the number on the old part which is replaced. The numbers on the drawing correspond to a key tabulation which follows under heading "Table of Fits—Wasp Engine."

Connecting Rods.—If excessive play has developed in the master rod big end bearing, this will have to be replaced. To do this requires special equipment. It is far better to replace the master rod assembly and send the old rod to the factory for re-bushing. If it is necessary to do this job in the field, proper equipment must be at hand and the following instructions should be noted. To remove the master rod bearings first take out

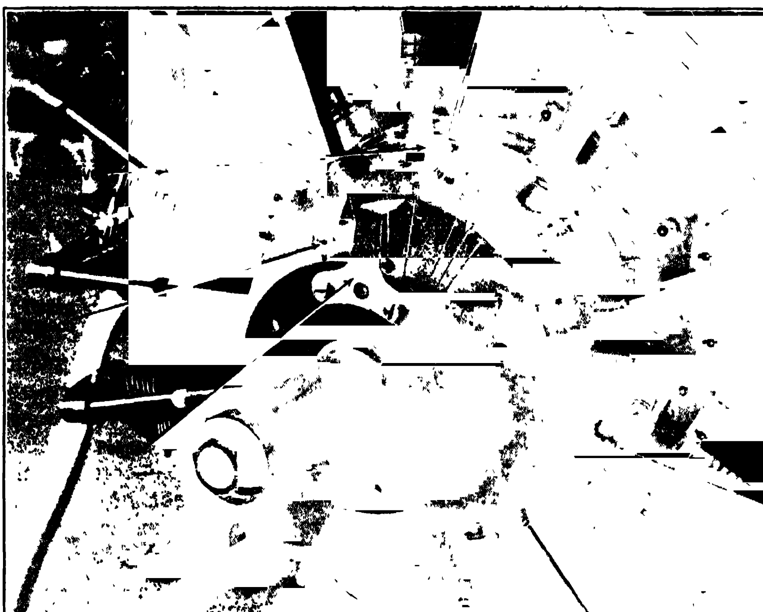


Fig. 636.—Method of Timing the Pratt & Whitney "Wasp" Engine. The Screwdriver is Inserted in Breather Hole for Separating Cam Drive Clutch Teeth. Pointer Must Register with TC Mark When No. 1 Piston is on Top Center.

the dowel screws and turn off one flange. Then press out both bushings at once, using a suitable arbor.

In order to put in new bushings, the master rod must be heated in oil to a temperature of about 250 degrees Fahrenheit. This will expand it enough so that the bearings can be tapped into place with a block of wood. It should not be necessary to drive hard, as this would be likely to crack the babbitt. After the bushings are in place, the holes for the locking screws should be drilled. A No. 4 (.209 inch) drill is used and one hole is required in each bushing, using the tapped hole in the master rod as a guide. Take pains not to damage the threads. The inside of each hole should be chamfered about .010 inch where it comes through the babbitt.

The screws can then be put in place and secured by using a center punch on the master rod alongside the screw holes. The locking pins must not project all the way through the bearings.

A special fixture is required for reaming the new bearings. The reamers must be kept sharp. Use a mixture of equal parts of lard, oil and kerosene for a lubricant while reaming. The clearance should be .0025 inch to .003 inch on the diameter and .012 inch on the length. The end clearance is very important and should be obtained by equal scraping on both bushings. The crankpin should be blued and the bearing tested. If the reaming has been properly done no scraping should be necessary but it is advisable to burnish the bearing. Clean out the holes which supply the knuckle pins with oil and make sure they communicate with the main bearing holes.

The piston pin and knuckle pin bushings are held in by brass pins .163 inch diameter by $^{11}/_{64}$ inch long. These must be drilled out with a No. 21 drill before trying to remove the bushings. A suitable drift should be provided for pressing out the bushings, using an arbor press if one is available. When inserting a new bushing, have the oil holes properly lined up and white lead the bushing before pressing it into position. The locking pin hole is not drilled all the way through the bushing, but just deep enough to receive the pin. Slightly rivet over the edge of the hole after the pin is put in.

Pistons and Rings.—If it should be necessary to replace a piston, the new piston must not be more than .03 pounds ($^1/_2$ ounce) different in weight from the one it replaces. The weight of the piston will be found on the under side of the skirt. The lower end of the piston may be bored out for balancing, but not larger than $5^1/_8$ inch diameter. Two types of pistons are in use. Navy engines after No. 286 and Commercial engines after No. 730 have heavier pistons than formerly used, and replacement must be made accordingly. **Caution: The heavy pistons cannot be used in the earlier engines which have light counterweights.** When new rings are fitted, the end clearance should be between .008 inch and .015 inch. The side clearance for the top ring should be .004 inch. The next two rings should have .002 inch to .0025 inch and the bottom ring .0015 inch to .002 inch.

Valves.—Full instructions for grinding valves are given in the section on Top Overhaul.

Replacing Valve Guides.—The inlet and exhaust stems are of different diameters and it will be found that the station tool equipment includes two sets of tools for handling the valve guides. A puller is provided for removing the guides. Before using it, it is well to examine the lower end of each guide to make sure it is not swelled out or burred over, as this would cause splitting of the boss in the cylinder head if the burr is not removed before forcing the guide out. After removing the guide, see that the hole in the cylinder head is clean and free from roughness and also examine the new guides for burrs. Drifts are furnished for driving guides in. Smear the guides with white lead and heat the cylinder head to about 200 degrees Fahrenheit before trying to put in the new guides. Heating can be accomplished by directing a gentle blow-torch flame on the aluminum guide boss

inside the port. Reamers and plug gauges are supplied and each new guide must be carefully reamed to fit the proper gauge.

Studs.—Whenever a stud is taken out of any aluminum part, it must be replaced with an oversize stud in order to have a tight fit. Oversize studs are furnished with the spare parts, and must be cut off to a suitable length.

Timing Gear Bushing.—If it is necessary to replace the timing gear bushing, part No. 1,015, see that the oil hole in the bushing lines up with the oil hole in the top of the boss. The proper clearance of the gear in the bushing is .002 inch on the diameter and .008 inch end clearance.

Assembling the Engine.—After the inspection has been made and necessary corrective work completed, the engine is ready for re-assembly. The "Wasp" engine may be assembled simultaneously in two units; namely, the power section and the accessory section. To do this requires two assembly stands. If these are not available, it is necessary to build up the accessory section first, and then use it as a holding fixture for the assembly of the power section.

It is absolutely necessary to have a clean, well-lighted work-room for the assembly of engines. The parts should all be carefully cleaned before the assembling is commenced and the greatest care should be taken to avoid getting dirt into the engine as it is built up. The various bearings should be smeared with clean engine oil as the parts are being put together. It is well to inspect all parts for slight burrs or nicks that may have resulted from rough handling or other accidental causes. If any such are found they must, of course, be removed before the parts are put together. The various nuts, bolts and other fastenings of the engine are all secured by some kind of locking device. As soon as each part is assembled, the cotter pin, wire or other lock should be put in. If this is not done immediately, it is likely to be forgotten, and a forced landing may result.

Safety Locking Devices.—The following special locks are used in the Wasp engine, and must be put in place when the engine is assembled:

Part Name	*Kind of Lock*	*Part No.*
Pin—Art Rod	Plate	A—1258
Nut—Blower Impeller	8 Penny Nail	A—839
Coupling—Magneto	Snap Ring	A—817
Nut—Inlet Pipe	Palnut	A—818
Nut—Exhaust Flange	Palnut	A—818
Nut—Rear Section to Blower Section	Palnut	A—818
Pin—Gun Control Coupling	Snap Ring	A—805
Valve—Inlet	Snap Ring	A—1082
Valve—Exhaust	Snap Ring	A—1081

The following parts are secured with cotter pins:

Part Name	*Size of Cotter*
Bolt—Crankshaft	5/64" x 1"
Bolt—Main Crankcase	3/32" x 3/4"
Pin—Starter Jaw	1/16" x 1/2"
Nut—Blower Shaft	5/64" x 1 1/4"
Nut—Blower Int. Shaft	5/64" x 3/4"
Screw—Magneto Drive Shaft	5/64" x 1 1/2"

Nut—Propeller Hub .... $\frac{3}{16}$" x $3\frac{1}{2}$"
Bolt—Rocker Arm .... $\frac{1}{16}$" x $\frac{1}{2}$"

The nuts holding the following parts are secured with soft brass wire (metallic belt lacing) .052 inch diameter: Cylinder Flange, Cylinder to Crankcase, Blower to Main Case, Front Section to Main Case, Front Bearing Cover.

The nuts or screws holding the following parts are secured with soft brass wire (metallic belt lacing) .040 inch diameter: Bracket—Oil Feed Bearing, Capscrew—Inlet Pipe, Carburetor, Cover Blower Bearing, Cover—Generator Hole, Cover—Gun Control, Cover—Magneto Drive, Cover—Oil Screen, Gear—Crankshaft Rear, Guide—Valve Tappet, Lock—Knuckle Pin, Magneto, Pipe—Oil, Pump—Fuel, Pump—Oil, Sump, Tachometer Drive.

Blower Section.—After the blower section has been thoroughly cleaned it can be bolted to the assembling stand with the oil sump connection at the lowest point. The blower impeller shaft and bearings may then be put in place and next the blower intermediate. The intermediate shaft gear should be put on and then by using the blower gear holder furnished in the station tool equipment, the rear nut of the intermediate shaft and the front nut of the impeller shaft can be properly tightened. These two nuts are secured by cotter pins. The bearing cover is held against the blower casting by eight screws and a gasket is used between the cover and the casting. A new gasket should be used and shellacked to the cover, which should be carefully cleaned. Oil the other side of the gasket. See that the oil slinger is in place on the impeller shaft. After the cover has been made fast and wired, the impeller is pushed on the shaft and the cone shaped impeller nut secured. A special screwdriver for tightening this nut is supplied and the blower gear holder is used to hold the gears stationary while this is being done. Do not use a screwdriver between the gears to hold them, but use the gear holder which is made for that purpose. Be sure that the impeller nut is screwed up as tight as possible and then put the safety pin in place This pin should be made from an eight penny nail and is bent over at both ends to hold it in place.

Turn the blower section over so the front side is on top. Examine the floating blower drive gear and its bushing. The latter should be a tight fit on the boss of the blower casting, and in any case, not more than .0005 inch loose on the diameter. The bearing surfaces of the bushing and gear must be in good condition and the clearance between them should not be more than .008 inch. Be sure that the oil passage which feeds this bearing is open and that the holes register. Oil the gear, put it on the bushing, and tap the bushing into place, fastening it with the six small screws. These must be wired. The end clearance between the gear and the flange of the bushing should not be more than .010 inch. (These directions are of course, unnecessary on engines having a double gear on the rear of the crankshaft.) Put the pressure oil pipe in place. While the casting is in this position, make sure that the various plugs in the front face of the blower are tight. Any looseness can be remedied by carefully peining the casting around the edge of the plug. When everything is in order here, reverse the assembly stand so that the rear side of the blower will be uppermost.

Rear Section.—The rear casting may now be placed upon the blower. The greatest care must be taken to guide the rear section perfectly straight while it is being brought down into position. Three drive-shaft bushings and the oil pressure pipe have to be entered into their respective holes, and damage will result unless they are carefully guided. Care must be taken in handling the rear section to see that the oil pressure transfer pipe is not damaged. There is a gasket between the rear and blower sections. This need not be replaced unless it is in poor condition. The nuts which fasten the rear section to the blower section must be locked with palnuts.

It may sometimes happen that the blower section will already be attached to the main crankcase when the rear section is put onto the blower, as for instance, when the rear section has been removed from the engine without the latter being completely disassembled. In such a case, the gun control shafts must first be assembled in the rear section, leaving the cover plates loose to be fastened later.

Next, turn the assembly into the operating position and insert the starter shaft and put on the starter jaw. This is secured with a straight pin which in turn is fastened with a cotter pin. Before putting the magneto drive shafts in place, the vertical shafts which drive the gun synchronizers must be put in through the pump openings. The gun control shafts should not be secured at the top until after the driving bevel gears are in place, as these shafts have to be lifted up to let the gears pass. The magneto drive shafts are then assembled in place and the keys put in these shafts and the bevel gears are put on. The magneto drive covers are now put on and their screws wired up; before doing this, however, inspect the leather oil retainers to insure that they are in good condition.

The magneto coupling is held by a screw in the end of the shaft and this screw is secured by a cotter pin. The upper cover plates for the gun control shafts can now be screwed down and the gun control couplings screwed on the ends of the shafts. These couplings are held on by straight pins and a snap ring goes around each one to hold the pin in place. Test all the gears for backlash. The bevel gears which drive the gun controls, oil pump, and fuel pump should have .004 inch to .012 inch backlash. New bushings must be faced off to make the gears mesh properly.

The oil pump parts should be well oiled when they are put together. The pump can then be assembled into the rear casting. Put on the fuel pump and put the oil strainer and strainer cap in place. The starter should be put on before the magnetos, as this makes it easier to get at the nuts. Follow up with the magnetos and carburetor. Pay no attention to the timing of the magnetos when putting them on. The adjustable couplings allow them to be timed after the engine is completely assembled. The ignition wire tube with the wires and magneto distributor blocks should be left off until the rest of the engine is assembled. As soon as the accessories are all in place, turn over the assembly stand so that the accessory drive gears are facing upwards. Then put the rear half of the main crankcase in place, first being sure that all nine of the main case bolts are in position. There is no gasket between this piece and the blower section.

Connecting Rods.—Assembling of the master rod should be done on the bench. It will be found that the master rod is marked to show which

side goes toward the front or propeller end of the engine. It must be assembled on the shaft with the knuckle pin locking plates toward the rear. Each link rod is numbered on the rear side to correspond with the cylinder in which it works, and the master rod is also numbered alongside of the respective knuckle pin holes. The knuckle pins push in place easily for a certain distance but must be pressed home with considerable force. They are best put in place in pairs with the locking plate between the two knuckle pins. The pins and the link rod bushings must be liberally smeared with oil. The two knuckle pins are tapped in place at the same time by using a block of hard wood and a hammer. Fasten all locking plates with the fillister head screws and immediately wire the screws.

Crankshaft.—Before starting to assemble the crankshaft, make sure it has been thoroughly cleaned and the surfaces do not show any burrs or other roughness. The best way to hold the crankshaft is to grip the counterweight of the front half in a soft-jawed vise as previously described and illustrated The screw plug No. A-127 is put in place in the rear end of the front or main half of the shaft and locked by punching the edge of the plug into a hole in the shaft. If this plug has been defaced in removing it, a new one should be used. Oil the master rod bearing thoroughly and put the connecting rods in place with the knuckle pin locking plates toward the rear. Gredag should be smeared in the hole in the crankpin and also on the rear part of the shaft which pushes into this hole. Do not use white lead as it dries and fills up the oil holes.

Insert the hardened steel washer A-1,433 in place on the rear end of the crank pin. If this does not stay in position, it may be stuck on with a little grease. The rear half of the shaft may now be offered up. It should be pulled into place by using the special puller furnished for this purpose. Hammering on the shaft should be avoided, but if absolutely necessary should only be done with a lead hammer or aluminum drift.

The crankshaft bolt after being thoroughly oiled may now be put in place and screwed up tight by means of the proper box wrench Do not try to use a monkey wrench for this job, as it is necessary to have this bolt screwed up hard. The cotter pin which secures the bolt is placed near the bolt head and a new hole will probably have to be drilled in the bolt at assembly for this cotter. It is not wise to allow more than three cotter pin holes to be drilled in the crankshaft bolt. If it has already been drilled three times, a new bolt should be used.

The rear main bearing may now be put in place, followed by the crankshaft rear gear. This gear is held on by four cap screws which should be wired up as soon as they have been tightened. If the engine is one which has a clutch to drive the blower, the special tool PWA-149 may be used to push the bearing into place. The gear will be held on by four countersunk head screws. These are covered by a steel clutch plate and need no other means of locking. The clutch parts can now be assembled according to the directions previously given. If the forward main bearing has been removed, it should now be replaced.

Assembling Rods and Shaft in Case.—As soon as the crankshaft as sembly has been made up with the rods on it and other parts, it should be lowered into the rear half of the main section which has been previously

attached to the blower section. The crankshaft should be kept in a vertical position and carefully lowered so that the blower, magneto and starting gears are meshed while it is still supported. It will be found as soon as the gears have entered that the assembly will go readily into place. Considerable damage may be done if an effort is made to force the shaft into position. Be sure that the master connecting rod is placed in cylinder No. 1. It will be found that the cylinder pads are marked on the front of the crankcase and that No. 1 is directly opposite the sump connections. Assemble the intermediate timing gear in the front half of the main case. This gear is held in by a special nut A-1,012 and a cotter pin locks this in place. With these parts assembled, the main case can be put on over the front bearing. This should now be slipped over the end of the crankshaft and put into position over the forward roller bearing. Gently tap the front half down into position. It may be necessary to push the end of the crankshaft slightly in one direction or another to make the crankcase bolt holes line up. When this is accomplished, the nine bolts should be tapped in place and their nuts screwed up and cottered. Be sure the cylinder pads are flush before tightening home the nuts.

The timing gear is now put on the crankshaft, with the driving dogs forward, after which the oil distributor bracket with its attached oil pipe can be fastened on. The cam drum is placed over its sleeve which is then slipped on the crankshaft and engaged with the keyways in the timing gear. All these parts must be copiously oiled before assembly. See that the cam drum has at least .010 inch end play. This is very important The crankshaft key should now be placed in its keyway and the timing sleeve slipped over it.

Next prepare the nose section for assembly. All the valve tappets and rollers should be re-assembled, after being well oiled. The thrust bearing should be placed in the nose and the whole assembly put in place. No gasket is used between the main crankcase and the front section. The crankshaft thrust bearing nut and oil slinger may now be screwed up, but not hard. This brings the crankshaft up into proper position in the center of the main crankcase and should be done before the crankshaft is turned around, as some damage may be done if it is turned around while it is resting on the rear main case. The thrust bearing cover need not be put on until after the engine is timed.

Cylinders.—The valves, valve springs and rocker arms should be assembled in the cylinders before the latter are put on the engine. A special tool is furnished for putting in and taking out the valve rocker pins. Full directions for assembling the pistons and cylinders are contained in the preceding section entitled "Top Overhaul." When the cylinders, push rods and intake pipes are in place, the oil sump is put on. Two oil connections are automatically made when the sump is put in place. Do not force the sump up if something prevents the pipes from going together. The suction pipe which takes oil from the bottom of the sump must have a good gasket and be bolted up tight.

Timing the Engine.—Two types of cam have been provided for Wasp engines. All engines prior to No. 286, and some with higher numbers, have a cam which gives the inlet valves a lift of $1\frac{1}{16}$ inch. All engines rated at

2,100 r.p.m. have a lift of $\frac{9}{16}$ inch for both inlet and exhaust valves. The difference may be determined by measuring the inlet valve lift, or by examining the cam. The high-lift cam has the internal gear teeth cut on the duralumin hub, while the low-lift cam has the teeth in the steel cam rim. A further difference that should be noted is in the valve springs. Heavy springs are used with the low-lift cam and light springs with the high-lift. In all cases the correct timing is indicated by marks on the front face of the front section of the crankcase.

To time the engine, have the thrust bearing cover off and slack off the thrust bearing nut two or three turns. Set the valves of No. 1 cylinder with .060 inch clearance on both intake and exhaust, being sure the cam is at the lowest point when this is done. (For the high-lift cam, use 050 inch on the inlet and .060 inch on the exhaust) This clearance is for timing only. Use the valve clearance gauge. When testing the valve clearance, the feeler is inserted between the valve stem and the valve adjusting screw ball. The valve rocker must be lifted up hard enough to overcome a light spring in the tappet. Slightly separate the teeth of the cam hub sleeve and the thrust bearing sleeve. This can be done by removing the front breather hole and using it to permit insertion of a tool to pry the sleeves apart Attach the timing disc to the front of the crankcase so that the top center mark is in line with No. 1 cylinder as shown at Fig. 636. If no timing disc is at hand, use the marks on the face of the crankcase front section. These will be seen when the thrust bearing cover is removed. Take out the screw plug near the front breather and insert the timing wrench so that its teeth engage the intermediate gear. Fasten a pointer to the crankshaft or propeller hub so that when No. 1 cylinder is on top dead center the pointer will register with the dead center mark on the timing disc.

Turn the crankshaft counter clockwise until the pointer comes to the inlet opening mark. Then turn the timing wrench counter clockwise until the inlet valve clearance is just taken up, the valve being about to open. Next, screw up the thrust bearing nut. Look through the breather hole and make sure that the teeth on the two sleeves are engaged and not riding on the tops of each other. After tightening the nut, check the inlet opening and exhaust closing again, when turning the shaft slowly in the normal direction (counter clockwise as seen from the front). After checking the timing, reset the clearance of both valves to .010 inch and see that the clearance of valves of the other cylinders is properly set to .010 inch.

Magneto Timing.—Magnetos should be set to break 30 degrees before top center when fully advanced. To time the magnetos, turn the crankshaft counter clockwise so the No. 1 piston is on the compression stroke (both valves closed) and the timing pointer registers with the "30 degree advance" mark on the front of the crankcase. Take off the magneto breaker covers and also the outside distributor blocks (the right hand block of the right magneto and the left hand one of the left magneto). Remove the lock wires from the magneto couplings and slip the couplings back (toward the magnetos) until they are disengaged. If the spark control rod is connected, place the control in the fully advanced position. Set each magneto to break for No. 1 cylinder. There is a window under the forward oil hole

cover on top of the magneto, and the figure (1) will appear under this window, when the magneto is in the right position.

If you cannot see this window, there are marks on the frame of the magneto alongside the distributor block, and on the brass gear inside. On the right side magneto two marks on the gear register with two marks on the frame and on the left magneto one mark on each part. Turn the gear with fingers until the marks register or until (1) appears in the little window. Hold the gear and turn the magneto coupling around until it goes into place. The breaker points should be closed, but just ready to open. Place a strip of cigarette paper between the breaker points of each magneto and adjust each magneto coupling so that the paper will just pull. To do this, hold the brass gear inside the magneto with the fingers, disengage the coupling and turn it one tooth backward (clockwise as viewed from the rear) and engage it again Repeat this with each magneto until the cigarette paper just becomes loose between the contacts.

Check the timing by turning the crankshaft clockwise half a turn and coming slowly up to the firing point, holding the cigarette papers and noting the exact point at which each one becomes loose Both magnetos must break at the same moment. After the setting is correct, put the snap rings on the magneto couplings. Put on the distributor blocks and the breaker covers, and secure with safety pins. Remove the timing pointer from the crankshaft, and put on the front bearing cover plate with the drain at the bottom. Screw up the cover plate nuts and wire them in place.

Running In.—After overhauling, the engine must be run in just as carefully as though it were new. It should be run under its own power for three to four hours at gradually increasing speeds. All external nuts should be examined for tightness after this period. In fact, it is well to omit the locking wires from the outside nuts until after running in, when everything may be tightened and then wired. If any new pistons or cylinders have been installed, the cylinders should be removed for inspection after the running in period. If new pistons, rings or bearings have been installed, the engine should be run in eight to ten hours and operated subsequently the same as a new engine. During the first ten hours of operation in the plane it is well to warm up the engine gradually after each start, and to stop gradually also, rather than shut off suddenly from full speed. During this period the engine should not be run wide open any more than is absolutely necessary, and sudden acceleration should be avoided. The same precautions apply to some extent at any time during the life of the engine. These measures, together with careful attention to maintaining the proper oil pressure and frequent change of oil, will result in polishing all moving parts so that long and trouble free service will be rendered.

Table of Fits—Wasp Engine

When three figures are given the second figure indicates the desired fit. The other two give the tightest and loosest fits permissible. Dimensions given in inches. Serial numbers refer to drawings at Figs. 621 and 622. The letter T means tight, letter L means loose.

1. Thrust Bearing and Case—End Clearance..........	.0036 T	.004 L	.0074 L
2. Thrust Bearing Cover Ring and Case—Dia	.0315 L	037 L	.0425 L
3. Thrust Bearing Cover and Case—Dia..............	0035 L	.005 L	.0065 L

4. Thrust Bearing and Case—Dia.	.0003 T	.001 L	.0015 L
5. Thrust Bearing and Spacer—Dia.	.000	.002 T	.0014 T
6. Thrust Bearing Spacer and Crankshaft—Dia.	.0005 L	.001 L	.0025 L
7. Crankshaft and Plug	.0005 T	.002 T	.0035 T
8. Thrust Bearing Spacer and Key—Side Clearance	.0005 T	.001 L	.0025 L
9. Crankshaft and Key	.0005 L	.000	.0015 T
10. Thrust Bearing Spacer and Key—Top Clearance	.007 L	.016 L	.025 L
11. Cam Drum and Spacer	.001 L	.003 L	.004 L
12. Cam Drum and Bushing	.0065 L	.008 L	.0095 L
13 Cam Drum—End Clearance—fit to	.000	.008 L	.000
14. Cam Drive Gear and Ring	.001 L	.001 T	.003 T
15. Cam Bearing Spacer and Gear—Lug Side Clearance	.000	.004 L	.008 L
16. Cam Drive Gear and Crankshaft—also Cam Bearing Spacer and Crankshaft	.0005 L	.001 L	.0025 L
17. Oil Distributor Bearing Bushing and Bracket	.000	.002 T	.004 T
18. Front Main Bearing and Crankshaft	.0003 L	.000	.0013 T
19. Front Main Bearing and Liner	.001 L	.0008 L	.0028 L
20. Front Main Bearing Liner and Case	.008 T	.010 T	.012 T
21. Front Main Bearing Liner and Case (Large Dia.)	.002 L	.005 L	.008 L
22. Crankshaft and Counterweight Rivet	.000	.001 T	.002 T
23. Crankshaft and Pin	.000	.0025 T	.005 T
24. Cam Drum and Cam	.0025 T	.001 T	.0005 T
25. Oil Feed Pipe, Upper and Bracket	.001 T	.000	.001 L
26. Oil Feed Pipe upper and Oil Feed Pipe lower	.000	.001 L	.002 L
27. Oil Feed Pipe lower and Oil Sump	.000	.001 T	.002 T
28. Crankcase Main and Front	.000	.001 L	.004 L
28. Crankcase Main and Blower	.000	.001 L	.004 L
28. Blower and Rear Case	.000	.001 L	.004 L
31. Main Crankcase and Bolt	.0005 T	.0015 L	.0015 L
32. Oil Sump and Pipe	.0005 T	.0015 T	.0025 T
33. Oil Sump and Strainer	.005 T	.015 L	.035 L
34. Oil Sump and Pipe	.000	.0015 T	.002 T
35. Oil Sump and Oil Pressure Pipe	.0005 T	.001 L	.0025 L
36. Cam Reduction Gear and Bushing—End Clearance	.004 L	.008 L	.012 L
37. Main Crankcase and Cam Reduction Gear Nut—End Clearance	.006 L	.011 L	.016 L
38. Cam Reduction Gear and Bushing—Dia	.001 L	.002 L	.003 L
39. Main Crankcase and Cam Reduction Gear Bushing	.001 T	.002 T	.003 T
40. Cam Reduction and Cam Countershaft Gear	.002 L	.000	.002 T
41. Valve Tappet Roller and Pin	.000	.001 L	.002 L
42. Valve Tappet and Valve Tappet Roller—Side Clearance	.008 L	.014 L	.020 L
43. Valve Tappet Guide and Roller—Side Clearance	.000	.003 L	.006 L
44. Tappet Guide and Pin	.002 L	.005 L	.009 L
45. Tappet Guide and Roller Pin—End Clearance	.021 L	.031 L	.041 L
46. Valve Breather and Valve Guide	.015 L	.018 L	.022 L
47. Valve Guide and Breather	.0005 T	.0035 L	.0065 L
48. Valve Guide and Valve	.003 L	.007 L	.010 L
49. Front Crankcase and Valve Guide	.0005 L	.000	.001 T
50. Valve Tappet and Valve Guide	.000	.0005 L	.001 L
51. Valve Tappet and Push Rod Socket	.0005 T	.0015 T	.0025 T
52. Push Rod Ball End and Push Rod	.0005 T	.0015 T	.0025 T
53. Push Rod Ball End and Pin	.009 T	.000	.014 T
54. Push Rod Tube inner and outer	.002 L	.004 L	.006 L
55. Cylinder Head and Valve Seat	.0065 T	.008 T	.0095 T
56. Exhaust Valve and Valve Guide	.005 L	.006 L	.007 L
57. Cylinder Head and Valve Guide—Inlet and Exhaust	.0005 T	.002 T	.0025 T
58. Cylinder Head and Push Rod Tube	.020 L	.010 L	.005 T
59. Cylinder Head and Rocker Cover Dowel	.001 L	.004 L	.007 L
60. Inlet Valve and Lock End Clearance	.001 L	.004 L	.007 L

61. Inlet Valve and Valve Guide	.0015 L	.002 L	.0035 L
62. Piston and Cylinder Sleeve (upper)	.036 L	.038 L	.040 L
63. Piston and Cylinder Sleeve (lower)	.028 L	.030 L	.032 L
64. Piston Pin and Plug	.0015 T	.0025 T	.0035 T
65. Master Rod and Bushing	.0015 T	.002 T	.0045 T
66. Piston Pin and Bushing	.00175L	0025 L	.00325L
67. Piston and Piston Pin	.00015L	.0008 L	.00125L
68. Cylinder Sleeve and Piston Pin Plug—End Clearance	.036 L	052 L	068 L
69. Main Crankcase and Cylinder Sleeve	002 L	.007 L	.012 L
70. Crankshaft Front and Crankshaft Rear—Large Dia	.000	.0005 T	.001 T
71 Master Rod and Bearing	.000	.001 T	.002 T
72. Starter Gear and Spacer	004 T	.000	.004 L
73 Crankshaft Front and Bearing	000	.0015 L	.002 L
74 Crankshaft and Bearing -End Clearance	0065 L	.012 L	0195 L
75 Crankshaft Rear and Bolt	001 L	003 L	.005 L
76 Articulated Rod Pin and Master Rod	.0005 L	.000	.001 T
77 Articulated Rod Pin and Plug	000	.0015 T	.003 T
78. Master Rod and Bushing—End Clearance	Fit to .006" L to 008" L At Assembly		
79. Articulated Rod and Master Rod—End Clearance	.011 L	015 L	.019 L
80. Master Rod and Articulated Rod Pin	.0005 L	.000	.001 T
81 Articulated Rod Pin and Bushing	.001 L	0015 L	.0025 L
82 Articulated Rod and Bushing	0015 T	002 T	0045 T
83. Rear Main Bearing and Liner	.0003 T	.0008 L	.0015 L
84 Crankshaft and Main Bearing—Rear	.0001 L	000	.0015 T
85 Main Bearing Liner Rear and Crankcase	008 T	.010 T	.012 T
86 Main Bearing Liner and Pin	.004 T	.001 T	003 L
89 Blower Intermediate Gear and Shaft	0005 L	.000	.0015 T
90. Intermediate Gear Shaft and Ball Bearing	.002 T	.000	0007 L
91 Blower Intermediate Cage and Case Small Dia	.000	.001 T	.002 T
92 Blower Intermediate Cage and Ball Bearing	0002 T	0006 L	.0016 L
93. Blower Intermediate Shaft and Spacer	0048 L	.010 L	.0153 L
94 Blower Intermediate Cage and Case—Large Dia	002 T	000	.002 L
95 Blower Bearing Cover and Case	002 L	.006 L	.010 L
96. Oil Screen Ferrule and Case	.000	010 L	020 L
97 Blower Shaft and Ball Bearing	0004 T	000	.0004 L
98 Blower Shaft and Slinger	000	.0005 T	.0014 T
99 Blower Shaft Bearing Cage and Case	000	001 T	.002 T
100 Blower Shaft Bearing Cage and Ball Bearing	0003 T	.0006 L	.0015 L
101 Blower Shaft and Impeller Spline Fit—Outside Dia	000	001 L	.002 L
Blower Shaft and Impeller Spline Fit—Inside Dia	000	.001 L	004 L
Blower Shaft and Impeller Spline fit—Width	.0005 T	0002 L	.0015 L
102 Blower Shaft and Jaw Spline—Outside Dia	.0005 T	002 L	0035 L
103 Blower Shaft and Jaw Spline—Inside Dia	.001 L	.002 L	.005 L
104 Blower Shaft and Jaw Spline—Side Clearance	.001 L	.001 L	.005 L
105 Blower Shaft and Bushing	.001 L	.002 L	.003 L
106 Blower Shaft and Ball Bearing	.000	.0005 T	.001 T
107 Blower Case and Ball Bearing	.0004 L	.001 L	0014 L
108. Blower Case and Discharge Plate	.010 L	.020 L	.030 L
109 Crankshaft and Oil Slinger	.000	.004 L	.008 L
110 Blower Case and Starter—Shaft Bushing	.0005 T	.0005 L	.0015 L
111 Rear Case and Starter—Shaft Bushing	.0005 T	.002 T	.0025 T
112 Rear Case and Starter	.001 L	.004 L	.007 L
113 Rear Case and Carburetor Elbow Cover	.000	.004 L	.008 L
114 Cylinder Head and Rocker Shaft -Ball Bearing	.0003 T	.0008 L	.0013 L
115 Rocker Shaft and Ball Bearing	.0001 L	000	.0007 T
116. Valve Rocker and Shaft (Diameter)	.0004 L	.000	.0004 T
117. Valve Rocker and Shaft—End Clearance	.0004 T	.006 L	.0156 L
118. Cylinder Head and Rocker Bearing Cover	.000	.004 L	.008 L

119. Rocker Bearing Cover and Bolt........	.000	004 L	.009 L
120. Gun Control Gear and Pin	.002 T	0005 T	.004 L
121. Gun Control Cover and Nut..............	001 L	005 L	.009 L
122. Gun Control Gear and Nut..........	.0013 L	0025 L	.0037 L
123. Gun Control Gear and Ball Bearing......	.0005 T	000	.0003 L
124. Gun Control Cover and Rear Case	.0005 T	001 L	.0025 L
125. Gun Control Cover and Ball Bearing......... ..	0006 L	001 L	.002 L
126 Magneto Advance—Yoke and Pin	.0005 T	001 L	.0025 L
127. Oil Pump End Plate and Body.................	000	001 L	.004 L
128 Oil Pump Body and Rear Case......	.000	002 L	.002 L
129 Oil Pump Body and Oil Pump Pressure Body ...	.000	001 L	004 L
130 Oil Pump Drive Gear and Key...	001 T	0005 L	001 L
131. Oil Pressure Gear and Key	.001 T	0005 L	.003 L
132. Oil Suction Idler Gear and Body—End Clearance .	.001 L	003 L	005 L
133. Oil Pump Drive Gear and Oil Pump Idler Shaft in Oil Pump End Plate	.001 L	002 L	.003 L
134. Oil Pressure Idler Gear and Oil Idler Suction Gear in Oil Pump Body and Oil Pump Pressure Body	005 L	007 L	.009 L
135. Rear Case and Dowel...	.000	0015 T	.003 T
136. Oil Pump Pressure Body and Dowel	.000	0005 L	.002 L
137. Oil Pump Idler Shaft and Oil Pump Drive Gear in Oil Pump, Pressure Gear and Oil Pressure Pump Idler Gear	.0005 T	.0005 L	.0015 L
138. Oil Pressure Idler Gear and Oil Pump Pressure Body—End Clearance	.001 L	003 L	.005 L
139. Oil Pressure Relief Body and Plunger	002 L	003 L	.006 L
140. Tachometer Drive Gear and Rear Case . . .	001 L	002 L	003 L
141. Tachometer Drive Gear—End Clearance	001 L	010 L	.025 L
142. Tachometer Drive Gear and Insert	0008 T	002 T	0038 T
143. Tachometer Drive Gear and Coupling	001 L	002 L	.003 L
144. Tachometer Coupling and Rear Case.	.000	002 L	004 L
145. Magneto Drive Gear and Shaft	001 T	000	001 L
146. Blower Case and Magneto Drive Bushing—Short.	.0005 T	002 T	.0025 T
147. Magneto Drive Shaft and Bushings .. .	001 L	002 L	003 L
148 Blower Case and Magneto Drive Bushing—Long	0005 T	0005 L	.0015 L
149. Rear Case and Magneto Drive Bushing—Long	.0005 T	002 T	0025 T
150. Magneto Drive Shaft and Fuel Pump and Gun Control Drive Gear......	0005 T	001 L	.0025 L
151. Fuel Pump Drive Gear and Bracket	001 L	002 L	003 L
152. Rear Case and Fuel Pump Drive Bracket	.000	001 L	004 L
153 Rear Case and Magneto Dowel . . ... ,	.0005 T	0015 T	0025 T
154. Gun Control Bushing and Rear Case	.001 T	002 T	.003 T
155. Gun Control Bushing and Gun Control and Tachometer Drive Gear	001 L	002 L	.003 L
156. Key in Fuel Pump and Gun Control Drive Gear....	.0005 L	001 L	.0035 L
157. Magneto Drive Shaft and Key	.001 T	000	.002 L
158. Fuel Pump and Gun Control Drive Gear and Key—Top Clearance	.007 L	.012 L	.017 L
159. Magneto and Dowel......................... ..	.000	.001 L	.003 L
160. Rear Section Pressure Pipe in Rear Case—Upper...	.000	.001 T	.002 T
161. Oil Pressure Pipe Rear and Rear Section...	.000	.001 T	.002 T
162. Rear Section Pressure Pipe in Rear Case—Lower...	0005 T	002 T	0025 T
163. Oil Pressure Pipe Rear and Blower Section	000	0005 L	.002 L
164. Blower Section Oil Pressure Pipe and Bracket ...	0015 T	.0015 T	.0045 T
165. Steel Propeller Hub Snap Ring and Propeller Hub—Side Clearance	001 L	.004 L	.007 L
166. Crankshaft and Propeller Hub—Side Clearance....	0005 L	.001 L	.0035 L
167. Crankshaft and Propeller Hub—Outside Dia	005 L	010 L	014 L
168. Crankshaft and Propeller Hub—Inside Dia	.001 L	.010 L	.015 L
169. Propeller Hub Clamp, Female and Head Pin.......	000	.001 L	.003 L

170. Crankshaft Rear and Crankshaft Front—Small Dia..	0005 T	.001 T	.0015 T
171 Oil Feed Bearing Bracket Dowel in Main Crankcase	000	0015 T	.003 T
172 Oil Feed Bearing Bracket and Dowel......... ..	000	.0005 L	.002 L
173. Blower Shaft and Spacer....	000	.001 L	002 L
174. Blower Shaft Ball Bearing Closure and Blower Shaft Bearing Cage..................... ..	0005 T	0005 L	.0015 L
175. Blower Impeller and Case (fit to .015 to .020″)			
176. Magneto Drive Cover and Rear Case	000	.006 L	.012 L
177 Magneto Drive Oil Shield and Rear Case	000	.002 L	004 L
178 Fit at Assembly to .008″ End Clearance			
179 Fit at Assembly if necessary			
180 Fit flush at Assembly			
215 Rear Crankcase and Generator Support and Generator	000	.002 L	.004 L
216 Generator Drive Gear and Ball Bearing I D	0001 L	.0005 T	0009 T
217 Generator Support and Ball Bearing O D	0005 T	.0005 L	0013 L
218 Generator Support and Ball Bearing End Clearance	0013 L	.003 T	.0077 T
219 Generator Pinion and Starter Gear O.D	002 L	008 L	014 L
220 Generator Pinion and Starter Gear O.D	002 L	.010 L	.018 L
221 Generator Pinion and Starter Gear Width	000	.002 L	.004 L
222 Valve Adjusting Screw and Plug	000	.003 T	.006 T
223 Blower Drive Gear Bushing and Gear	006 L	.007 L	.008 L
224 Blower Drive Gear Bushing and Blower ..	0005 L	.001 T	0025 T
225 Valve Rocker Bearing Bushing and Cylinder Head	001 T	002 T	.004 T
226 Valve Rocker and Cup	000	.001 T	0025 T
227 Floating Blower Drive Gear End Clearance... . .	004 L	.007 L	.010 L

Description of the "Hornet" Engine.—The Pratt & Whitney "Hornet" engine is of the same general design as the "Wasp" but is larger. The "Hornet" has nine radial cylinders of 6¼ inch bore and 6¾ inch stroke. The outstanding features of the "Wasp" are also embodied in the "Hornet" and include a one-piece master connecting rod, two-piece crankshaft, forged duralumin crankcase, enclosed valve gear, built in supercharger, and the grouping of all accessories at the rear. The propeller end is shown at Fig. 637, the main dimensions in the assembly drawing at Fig 638.

Interchangeability with "Wasp."—The design of the "Hornet" engine is such that 87 per cent of the parts used in its construction are interchangeable with the similar parts of the "Wasp" engine. The rear half of the engine and all accessories but the starter are identically the same as those used on the "Wasp." In addition to these, the sump and many of the small engine parts are interchangeable. This system of construction has the highly desirable result of reducing the quantity of parts that must be carried in reserve where both the "Wasp" and "Hornet" engines are used.

The main crankcase, nose section, crankshaft, cam, pistons and cylinders are larger than the corresponding "Wasp" parts. Tappets, breather and some of the push rod cover parts are the same pieces used on the "Wasp" but the tappet guides, valves, and valve springs are different. A larger size of starter is used and the carburetor is equipped with larger chokes.

Installation.—The same considerations apply to the mounting of the "Hornet" engine as to the "Wasp" and reference should be had to the notes in the chapter to follow on installation of similar engines. On account of the large size of the "Hornet" cylinder, free circulation of cooling air is essential and the cowling must be so constructed as to expose all of the cylinder head casting and at least a part of the cylinder barrel. There should be no large diameter cowling or exhaust manifold immediately back

of the engine to obstruct the flow of air away from the engine. It is also desirable to have a good circulation of air all around the crankcase of the engine and around the oil tank to assist in keeping the oil cool. A three bladed propeller should be used.

Operation.—Refer to instructions previously given for operation of Pratt & Whitney engines. These apply equally to "Wasp" and "Hornet" engines. An additional precaution is necessary, however, in the case of the

Fig. 637.—Propeller End View of Pratt & Whitney "Hornet" Engine.

latter owing to the larger size of propeller used. Do not operate the engine at full throttle on the ground longer than necessary to check the maximum speed. The effective part of the propeller blade is so far removed from the crankshaft that insufficient cooling is provided for the engine while the plane is at rest, although the installation may be perfectly satisfactory while in the air.

Inspection.—The same rules apply for the "Hornet" as for the "Wasp." The valve clearance when cold is .010 inch for both inlet and exhaust. The

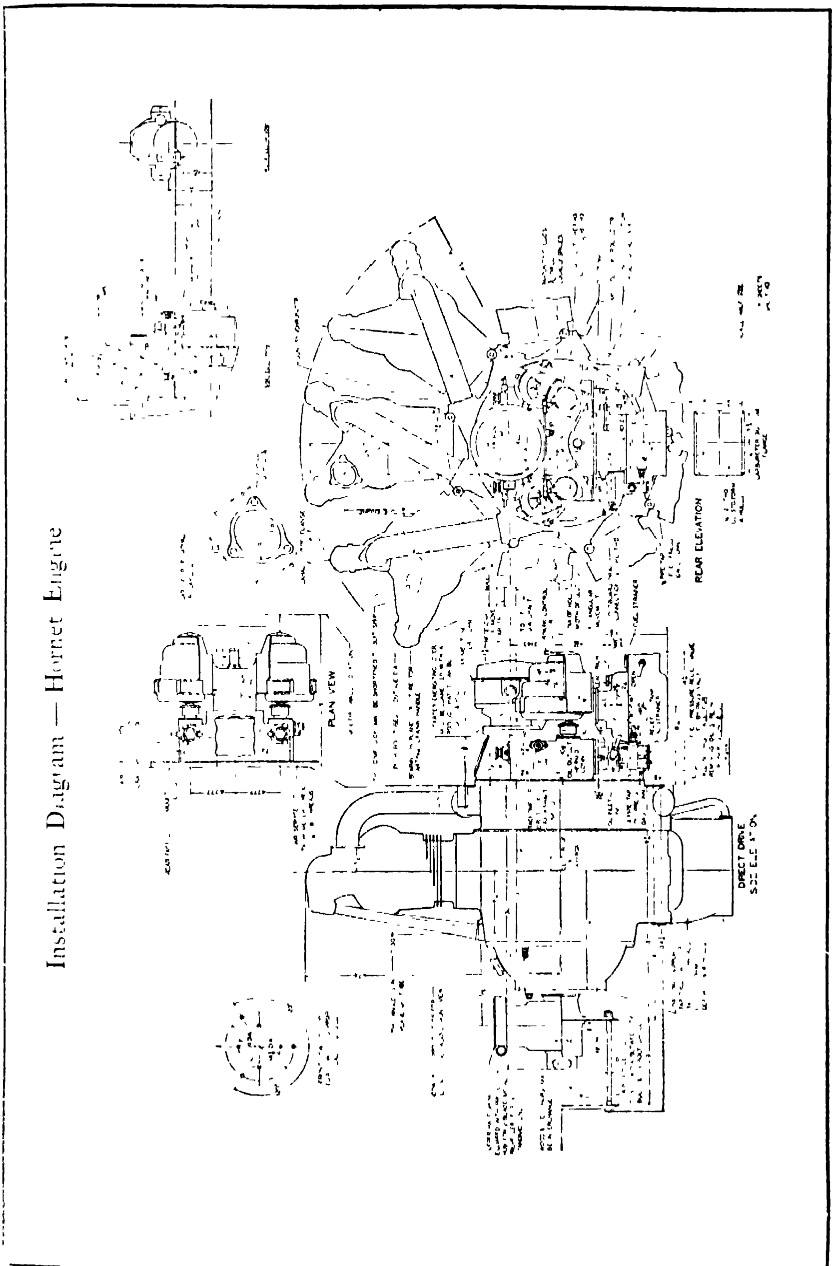


Fig. 638.—Installation Diagram of Pratt & Whitney "Hornet" Engine.

sectional diagrams at Fig 639 and 640 are the key drawings to the clearance tables that follow the specifications.

Overhaul.—The list of tools for assembling and disassembling Pratt & Whitney engines has been given on preceding pages and complete instructions for overhauling both types of engine. The instructions are written to specifically cover the "Wasp" and the following points of difference should be noted when working on the "Hornet" engine: The wood block which is placed inside the cylinder to facilitate handling the valves will be twelve inches long.

Timing.—When timing the "Hornet" engine, set the valves of No. 1 cylinder with .062 inch clearance (on both inlet and exhaust), being sure that the cam is at the lowest point when this is done After this proceed as described for the "Wasp" engine After completing the timing operation, set the clearance of all valves to 010 inch.

"HORNET" SPECIFICATIONS

Model	R1690
Rating (Military)	
Rated Power (doped fuel)	525 h p
Rated Speed	1900 r p m.
Rating (Commercial)	
Fuel Grade B Domestic Aviation Gas of sp gr. .682 or less	
Rated Power	500 h p
Rated Speed	1900 r p m.
General Form	
Cylinder arrangement	Radial
Number of cylinders	9
Cooling	Air
Bore Stroke	6 125"
Piston Displacement	6 375"
Compression ratio	5 00 1
Overall dimensions	
Outside Diameter	54½"
Mounting bolt circle diameter	23⅜"
Total length	44⅝"
Length back of mounting	14¼"
Distance from mounting to C. L. of propeller	25[illegible]"
Crankcase	
Material	Aluminium
No. of sections	5
Crankshaft	
Type	Single throw, 2-piece
Main Bearings	Ball or roller
Thrust Bearing	Ball type
Master Rod	
Type	One piece
Form of shank	I—section
Link Rods	
Form	I—section

Cylinders

Barrel	Steel
Head	Aluminum
Cooling fins	Integral

Valves

Number per cylinder	2
Material, inlet	Silchrome or Tungsten
Material, exhaust	C N S.
Lift, inlet	$\frac{11}{16}$"
Lift, exhaust	$\frac{9}{16}$"
Diameter inlet port	$2\frac{1}{2}$"
Diameter exhaust port	$2\frac{1}{2}$"

Valve Timing

Inlet opens	10° early
Inlet closes	60° late
Exhaust opens	71° early
Exhaust closes	31° late

Valve Springs

Number per valve	2
Form	Helical

Oil Pump

Type	Gear
Number of sections	2
Oil pressure	75-100 lbs.

Magnetos

Make	Scintilla
Number	2
Type	AG 9-D
Timing (full advanced)	30°
Direction of rotation	Clockwise

Sparkplugs

Type	B G. Hornet No. 4
Thread	18 m/m.

Tachometer Drive

Type	A S. Standard
Number	2
Rotation	Counter clockwise
Speed	$\frac{1}{2}$ crankshaft

Supercharger

Make	Gen Electric
Type	Centrifugal

Carburetor

Make	Stromberg
Type	NAY-7A
Number of barrels	2

Carburetor Setting

The test log sheet shipped with each engine gives details of jet and choke sizes for the individual engine ......

Standard Equipment and Weight

Weight of Hornet, with magnetos and carburetor, but no extras	765 lbs

The following accessories are shipped with each engine:

(weights not included in above) ....
Starting Magneto (Dixie 100) ... .8.3 lbs.
Primer . ... 5 lbs
Magneto Switch ... ... 9 lbs
Heater .... 10 0 lbs
Tool Kit ....11 9 lbs.

Additional Equipment
The following accessories can be supplied
Fuel Pump (C-5 type) . ...2 7 lbs
Hand Starter (Aeromarine Type D) including crank .30 3 lbs
Propeller Hub for metal blades .... .28 5 lbs
Gun Control Drive, as specified ....

Shipping Data
Overall size of box . ...60" x 60" x 52"
Weight, boxed .. . .1330 lbs approximate

Table of Fits—"Hornet" Engine

When three figures are given the second figure indicates the *desired* fit. The other two give the tightest and loosest fits permissible. Dimensions given in inches. Serial numbers refer to drawings, Figs. 639 and 640 where the parts referred to are designated by key numbers. For example, the crankshaft key is designated as No 9 on drawing Fig. 639. The key can be five-tenths of one-thousandth of an inch loose or one and one-half thousandths of an inch tight The desired fit is exact, neither tight nor loose.

8	Thrust Bearing Spacer and Key—Side Clearance	0005	T	001	L	0025	L
9	Crankshaft and Key	0005	L	000		.0015	T
10	Thrust Bearing Spacer and Key—Top Clearance	007	L	016	L	.025	L
11.	Cam Drum and Spacer	001	L	003	L	.004	L
13	Cam Drum End Clearance—fit to			008	L		
20	Front Main Bearing Liner and Case	008	T	.010	T	012	T
22.	Crankshaft and Counterweight Rivet	.000		001	T	.002	T
23	Crankshaft and Pin	.000		0025	T	005	T
24	Cam Drum and Cam	007	T	.009	T	.011	T
27.	Oil Feed Pipe lower and Oil Sump	000		001	T	.002	T
28.	Crankcase Main and Blower	.000		001	L	004	L
28.	Crankcase Main and Front	000		.001	L	.004	L
28.	Blower and Rear Case	000		001	L	004	L
31.	Main Crankcase and Bolt	0005	T	0015	L	0015	L
32	Oil Sump and Pipe	0005	T	0013	T	0025	T
33.	Oil Sump and Strainer	.005	T	015	L	035	L
34.	Oil Sump and Pipe	.000		0015	T	002	L
35.	Oil Sump and Oil Pressure Pipe	0005	T	001	L	0025	L
36.	Cam Reduction Gear and Bushing—End Clearance	004	L	.008	L	.012	L
37.	Main Crankcase and Cam Reduction Gear Nut—End Clearance	.006	L	.010	L	016	L
38.	Cam Reduction Gear and Bushing—Dia.	001	L	002	L	003	L
39.	Main Crankcase and Cam Reduction Gear Bushing	.001	T	.002	T	003	L
40	Cam Reduction—and Cam Countershaft Gear	.002	L	.000		002	T
41.	Valve Tappet and Pin	.000		.001	L	.002	L
41.	Valve Tappet Roller and Pin	.000		001	L	.002	L
42.	Valve Tappet and Valve Tappet Roller—Side Clearance	.008	L	.014	L	.020	L
43.	Valve Tappet Guide and Roller Side Clearance	000		003	L	.006	L
44.	Tappet Guide and Pin	.002	L	005	L	.009	L
45.	Tappet Guide and Roller Pin End Clearance	020	L	031	L	.041*	L
46.	Valve Breather and Valve Guide	015	L	.018	L	.022	L

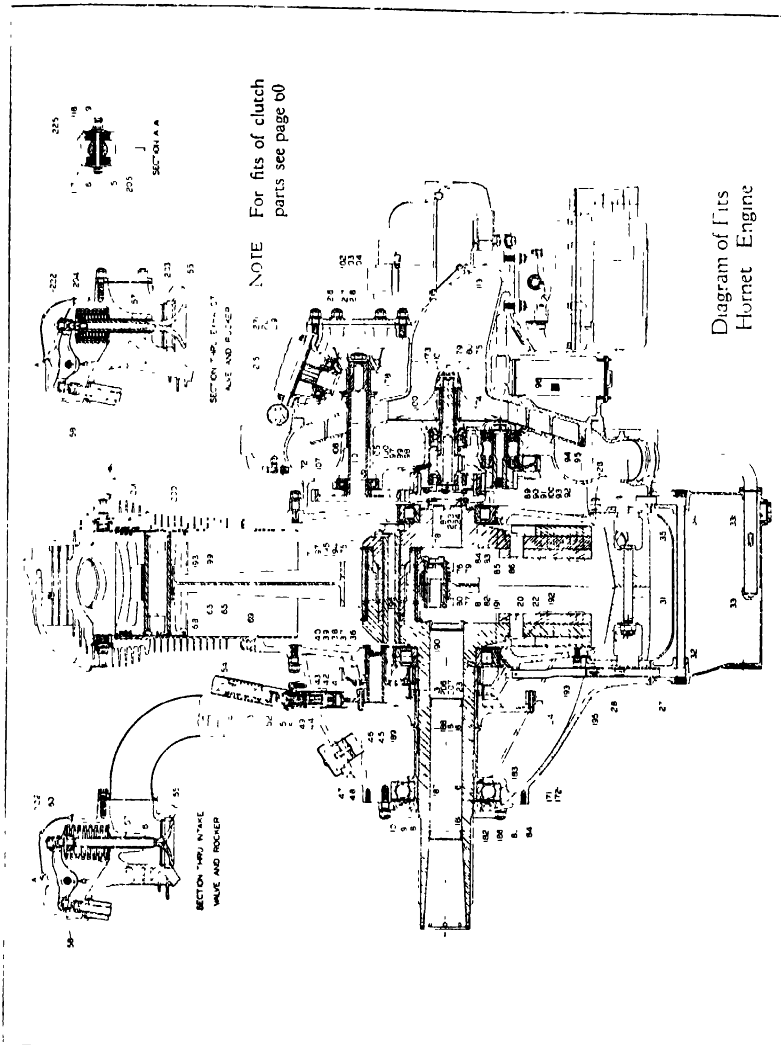


Fig. 639.—Numbered Key Diagram to Accompany Table of Fits for "Hornet" Engine. This Sectional View also Shows Construction of Engine.

47.	Valve Guide and Breather	.0005 T	.0035 L	.0065 L
48.	Valve Guide and Valve	.003 L	.007 L	.010 L
49.	Front Crankcase and Valve Guide	.0005 L	.000	.001 L
50.	Valve Tappet and Valve Guide	.000	.0005 L	.001 L
51.	Valve Tappet and Push Rod Socket	.0005 T	.0015 T	.0025 T
52.	Push Rod Ball End and Push Rod	.0005 T	.0015 T	.0025 T
53.	Push Rod Ball End and Pin	.009 T	.000	.014 L
54.	Push Rod Tube inner and outer	.002 L	.004 L	.006 L
55.	Cylinder Head and Valve Seat	.0065 T	.008 T	.0095 T
57.	Cylinder Head and Valve Guide—Inlet and Exhaust	.0005 T	.002 T	.0025 T
60.	Inlet Valve and Lock—End Clearance	.001 L	.004 L	.007 L

61. Inlet Valve and Valve Guide	.0015 L	.002 L	.0035 L
65. Master Rod and Bushing	.0015 T	.002 T	.0045 T
66. Piston Pin and Bushing	.00175 L	.0025 L	.00325 L
68. Cylinder Sleeve and Piston Pin Plug—End Clearance	.036 L	.052 L	.068 L
69. Main Crankcase and Cylinder Sleeve	.002 L	.007 L	.012 L
71. Master Rod and Bearing	.000	.001 T	.002 T
72. Starter Gear and Spacer	.004 T	.000	.004 L
75. Crankshaft Rear and Bolt	.001 L	.003 L	.005 L
76. Articulated Rod Pin and Master Rod	.0005 L	.000	.001 T
77. Articulated Rod Pin and Plug	.000	.0015 T	.003 T
78. Master Rod and Bushing—End Clearance	Fit to .006 L to .008 L At Assembly		

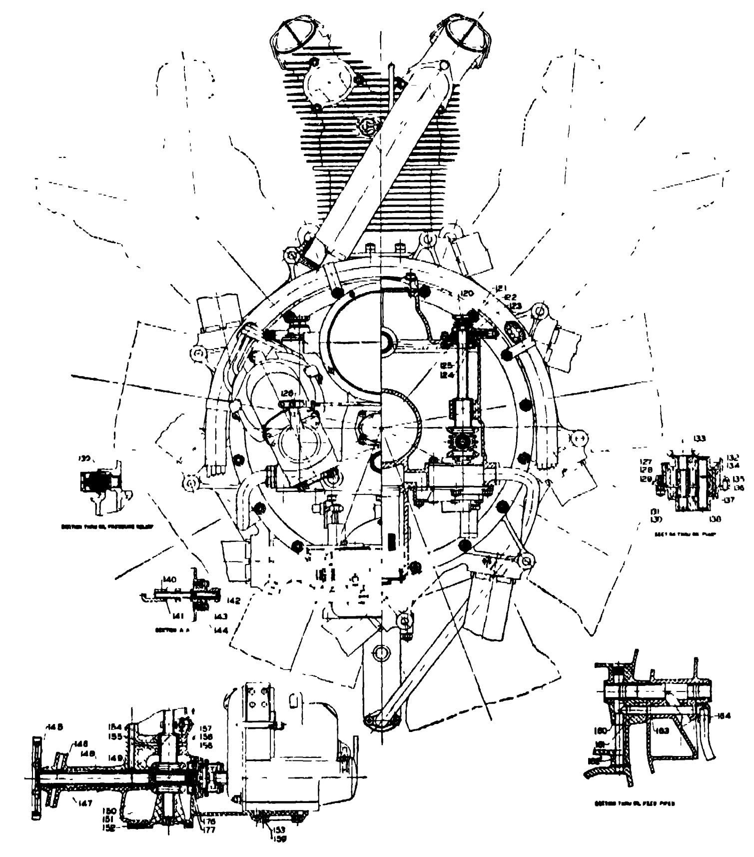


Diagram of Fits — "Hornet" Engine

Fig. 640.—Key Diagram to Accompany Table of Fits for "Hornet" Engine Parts Included in Accessory Drive Section.

79.	Articulated Rod and Master Rod—End Clearance....	011 L	.015 L	.019 L
80	Master Rod and Articulated Rod Pin Dia......... ..	0005 L	.000	.001 T
81	Articulated Rod Pin and Bushing............. ...	001 L	0015 L	0025 L
82	Articulated Rod and Bushing................ . .	0015 T	.002 T	0045 T
83	Rear Main Bearing and Liner............... .. .	0003 T	0008 L	.0015 L
84.	Crankshaft and Main Bearing—Rear	0001 L	.000	.0015 T
85	Main Bearing Liner Rear and Crankcase....	008 T	.010 T	.012 T
86	Main Bearing Liner and Pin	004 T	.001 T	.003 T
89	Blower Intermediate Gear and Shaft	0005 L	.000	.0015 T
90	Intermediate Gear Shaft and Ball Bearing—inside Dia	0002 T	000	0007 L
91	Blower Intermediate Cage and Case—Small Dia . ..	000	.001 T	.002 T
92	Blower Intermediate Cage and Ball Bearing—Outside Dia	0002 T	.0006 L	.0016 L
93	Blower Intermediate Shaft and Spacer	0048 L	010 L	.0153 L
94	Blower Intermediate Cage and Case—Large Dia ..	002 T	000	.002 L
95	Blower Bearing Cover and Case.	002 L	006 L	010 L
96	Oil Screen Ferrule and Case.	000	010 L	020 L
97	Blower Shaft and Ball Bearing.......	.0004 T	000	0004 L
98	Blower Shaft and Slinger......	.000	.0005 T	.0014 T
99	Blower Shaft Bearing Cage and Case. . . .	000	001 T	002 T
100	Blower Shaft Bearing Cage and Ball Bearing	0003 T	0006 L	0015 L
101	Blower Shaft and Impeller Spline Fit—Outside Dia	.000	.001 L	002 L
	Blower Shaft and Impeller Spline Fit—Inside Dia	000	001 L	.0025 L
	Blower Shaft and Impeller Spline Fit—Width... ..	0005 T	.0002 L	0015 L
102	Blower Shaft and Jaw Spline—Outside .	0005 L	002 L	0035 L
103	Blower Shaft and Jaw Spline—Side Clearance... ..	.000	.002 L	.004 L
104	Blower Shaft and Jaw Spline—Side Clearance .	000	001 L	004 L
105	Blower Shaft and Bushings	001 L	002 L	003 L
106	Blower Shaft and Ball Bearing	000	0005 T	.001 T
107	Blower Case and Ball Bearing	0001 L	.001 L	.0019 L
108	Blower Case and Discharge Plate.	010 L	020 L	030 L
110	Blower Case and Starter Shaft and Bushing.	0005 T	0005 L	0015 L
111	Rear Case and Starter Shaft Bushing	0005 T	002 T	.0025 T
112	Rear Case and Starter..........	001 L	.004 L	007 L
113	Rear Case and Carburetor Elbow Cover	000	.004 L	.008 L
115	Rocker Shaft and Ball Bearing.	0001 L	.000	0007 T
116.	Valve Rocker and Shaft—Dia.	.0004 L	.000	.0004 T
117	Valve Rocker and Shaft—End Clearance ...	0004 T	006 L	.0156 L
118	Cylinder Head and Rocker Bearing Cover.	000	004 L	008 L
119	Rocker Bearing Cover and Bolt.	000	.004 L	.009 L
120	Gun Control Gear and Pin........ . . .	002 T	.0005 T	004 L
121	Gun Control Cover and Nut..................	001 L	.005 L	.009 L
122	Gun Control Gear and Nut	0013 L	0025 L	0037 L
123.	Gun Control Gear and Ball Bearing	0005 T	.000	.0003 L
124	Gun Control Cover and Rear Case..... . .	0005 T	.001 L	.0025 L
125	Gun Control Cover and Ball Bearing.	.0006 L	.001 L	.002 L
126	Magneto Advance Yoke and Pin.......... ..	0005 T	.001 L	.0025 L
127	Oil Pump End Plate and Body...............	.000	.001 L	.004 L
128	Oil Pump Body and Rear Case.	.000	.002 L	.002 L
129	Oil Pump Body and Oil Pump Pressure Body	.000	001 L	.004 L
130	Oil Pump Drive Gear and Key..........	001 T	.0005 T	.001 L
131	Oil Pressure Gear and Key...........	.001 T	.0005 L	.003 L
132	Oil Suction Idler Gear and Body—End Clearance ...	001 L	.003 L	.005 L
133	Oil Pump Drive Gear and Oil Pump Idler Shaft in Oil Pump End Plate..........	001 L	.002 L	.003 L
134.	Oil Pressure Idler Gear and Oil Idler Suction Gear in Oil Pump Body and Oil Pp. Pressure Body	005 L	007 L	.009 L
135.	Rear Case and Dowel	000	.0015 T	.003 T

136. Oil Pump Pressure Body and Dowel	.000	.0005 L	.002 L
137. Oil Pump Idler Shaft and Oil Pump Drive Gear in Oil Pump Pressure Gear and Oil Pressure Pump Idler Gear	.0005 T	.0005 L	.0015 L
138. Oil Pressure Idler Gear and Oil Pump Pressure Body—End Clearance	.001 L	.003 L	.005 L
139. Oil Pressure Relief Body and Plunger	.002 L	.003 L	.006 L
140. Tachometer Drive Gear and Rear Case	.001 L	.002 L	.003 L
141. Tachometer Drive Gear—End Clearance	.001 L	.010 L	.025 L
142. Tachometer Drive Gear and Insert	.0008 T	.002 T	.0038 T
143. Tachometer Drive Gear and Coupling	.001 L	.002 L	.003 L
144. Tachometer Coupling and Rear Case	.000	.002 L	.004 L
145. Magneto Drive Gear and Shaft	.001 T	.000	.001 L
146. Blower Case and Magneto Drive Bushing—Short	.0005 T	.002 T	.0025 T
147 Magneto Drive Shaft and Bushings	.001 L	.002 L	.003 L
148 Blower Case and Magneto Drive Bushing—Long	.0005 T	.005 L	.0015 L
149. Rear Case and Magneto Drive Bushing—Long	.0005 T	.002 T	.0025 T
150. Magneto Drive Shaft and Fuel Pump and Gun Control Drive Gear	.0005 T	.001 L	.0025 L
151. Fuel Pump Drive Gear and Bracket	.001 L	.002 L	.003 L
152. Rear Case and Fuel Pump Drive Bracket	.000	.001 L	.004 L
153. Rear Case and Magneto Dowel	.0005 T	.0015 T	.0025 T
154. Gun Control Bushing and Rear Case	.001 T	.002 T	.003 T
155. Gun Control Bushing and Gun Control and Tachometer Drive Gear	.001 L	.002 L	.003 L
156. Key in Fuel Pump and Gun Control Gear	.0005 L	.001 L	.0035 L
157. Magneto Drive Shaft and Key	.001 T	.000	.002 L
158. Fuel Pump and Gun Control Drive Gear and Key—Top Clearance	.007 L	.012 L	.017 L
159. Magneto and Dowel	.000	.001 L	.003 L
160. Rear Section Pressure Pipe in Rear Case—Upper	.000	.001 T	.002 T
161. Oil Pressure Pipe Rear and Rear Section	.000	.001 T	.002 T
162. Rear Section Pressure Pipe in Rear Case—Lower	.0005 T	.002 T	.0025 T
163. Oil Pressure Pipe Rear—Blower Section	.000	.0005 L	.002 L
164. Blower Section, Oil Pressure Pipe and Bracket	.0015 T	.0015 T	.0045 T
171. Oil Feed Bearing Bracket Dowel in Main Crankcase	.000	.0015 T	.003 T
172. Oil Feed Bearing Bracket and Dowel	.000	.0005 L	.002 L
173. Blower Shaft and Spacer	.000	.001 L	.002 L
174. Blower Shaft Ball Bearing Closure and Blower Shaft Bearing Cage	.0005 T	.0005 L	.0015 L
175. Blower Impeller and Case	Fit to .015 L to .020 L		
176. Magneto Drive Cover and Rear Case	.000	.006 L	.012 L
177. Magneto Drive Oil Shield and Rear Case	.000	.002 L	.004 L
178. Fit at Assembly to .008" End Clearance			
179. Fit at Assembly if necessary			
180. Fit flush at Assembly			
181. Crankshaft and Plug	.002 T	.003 T	.006 T
182. Thrust Bearing and Case—Dia	.0002 L	.0002 T	.0016 T
183. Thrust Bearing and Case—Dia	.0002 T	.001 L	.002 L
184. Thrust Bearing Cover Ring and Case—Dia	.019 L	.025 L	.030 L
185. Thrust Bearing Cover and Case	.001 L	.002 L	.004 L
186. Thrust Bearing and Case—End Clearance	.0036 T	.004 L	.0074 L
187. Thrust Bearing Oil Slinger and Nut	.000	.001 L	.003 L
188. Cam Drum and Bushing	.006 L	.008 L	.010 L
189. Oil Distributor Bracket and Bushing	.0015 T	.003 T	.0045 T
190. Front Main Bearing and Crankshaft	.0003 L	.000	.0014 L
191. Front Main Bearing and Liner	.0005 T	.001 L	.0017 L
192. Front Main Bearing Liner and Case—Large Dia	.011 L	.031 L	.051 L
193. Oil Feed Pipe—Upper and Bracket	.000	.000	.002 L

194. Crankshaft and Bearing—End Clearance...........	.0065 L	.012 L	.0195 L
195. Crankshaft Front and Bearing....................	.001 L	.002 L	.003 L
196. Crankshaft Rear and Crankshaft—Small Dia.......	000	.0005 T	.001 T
197. Crankshaft Rear and Crankshaft—Large Dia	.000	.0005 T	.001 T
198 Piston Pin and Plug	.0025 T	.003 T	.0045 T
199. Piston and Piston Pin	00055T	0003 L	.00055L
200. Piston and Cylinder Sleeve—Lower.	030 L	033 L	.034 L
201 Piston and Cylinder Sleeve—Upper	043 L	.045 L	.047 L
203 Exhaust Valve and Valve Guide	0065 L	007 L	.0085 L
204 Exhaust Valve and Plug...	000	001 T	.002 T
205 Cylinder Head and Rocker Shaft—Ball Bearing .	000	0005 L	.0012 L
206. Cam Bearing Spacer and Ring.	000	006 L	.012 L
207. Cam Bearing Spacer and Ring—Big End Clearance	000	002 L	.008 L
208. Crankshaft and Propeller Hub—Outside Dia.. ...	004 L	.006 L	010 L
209. Crankshaft and Propeller Hub—Inside Dia	003 L	005 L	.009 L
210 Crankshaft and Propeller Hub—Side Clearance . ..	0007 L	001 L	0033 L
211 Crankshaft and Propeller Hub—Centering Cone	.0005 L	001 L	.0035 L
212 Propeller Hub Clamp—Male and Female—Side Clearance	000	002 L	.004 L
213. Propeller Hub Clamp—Male and Female and Pin...	000	001 L	.003 L
214. Propeller Hub Clamp—Male and Female and Bolt .	.0055 L	.010 L	.0315 L
215 Rear Crankcase and Generator Support and Generator	000	.002 L	.004 L
216. Generator Drive Gear and Ball Bearing I D.... ..	0001 L	.0005 T	.0009 T
217. Generator Support and Ball Bearing O D . ..	0005 T	.0005 L	.0013 L
218 Generator Support and Ball Bearing—End Clearance	0013 L	003 T	.0077 T
219 Generator Pinion and Starter Gear—O D	002 L	.008 L	.014 L
220 Generator Pinion and Starter Gear—I D	002 L	.010 L	.018 L
221 Generator Pinion and Starter Gear Width..........	.000	002 L	.004 L
222. Valve Adjusting Screw and Plug	000	.003 T	006 T
223 Blower Drive Gear Bushing and Gear...	006 L	007 L	.008 L
224 Blower Driver Gear Bushing and Blower..... .	.0005 L	.001 T	.0025 T
225 Valve Rocker Bearing Bushing and Cylinder Head. .	0015 T	002 T	.004 T
226 Valve Rocker and Cup	000	001 T	.0025 T
227 Floating Blower Drive Gear—End Clearance	.004 L	.007 L	.010 L

QUESTIONS FOR REVIEW

1 What is the difference between "Wasp" and "Hornet" Aero engines
2. What parts are interchangeable on these engines?
3. What is the construction of the "Wasp" crankshaft?
4 Outline proper operating conditions, "Wasp" engine.
5. Why should new engine be run carefully?
6. What parts of "Wasp" engine need periodic inspection?
7. When is a Top overhaul needed?
8 How are "Wasp" valves removed?
9. How is the accessory section dismantled?
10. Describe checking and adjustment of blower drive clutch.

CHAPTER XXXVI

MISCELLANEOUS AIR-COOLED ENGINES

Lorraine Aviation Motors—Wright "Tornado" V-1456 Engine—Cameron Fixed Radial Type Aero Engine—Curtiss Challenger—The Walter Castor Engine—Bristol Jupiter Engines—Bristol Reduction Gear—The Salmson AB9 Engine—Menasco-Salmson Model B2—Curtiss Chieftain Engine—Study of Various Engine Types—Nine Cylinder Single Row Radial—Fourteen Cylinder Two Row Radial—Twelve Cylinder Vee—Twelve Cylinder Hexagon Type—Armstrong-Siddeley "Leopard" Engine.

Air-cooled aviation motors are made in many types and sizes, and new models are being announced from time to time so it will be apparent that a consideration and description of all types is out of the question. The new designs offered differ only in matters of minor detail from the older types. For this reason some typical motors have been selected from the large number available and in view of the rather complete descriptions given in other chapters of this book of various popular types, it is believed that the descriptions which follow will prove adequate to give the reader a good idea of the characteristics of the typical designs illustrated and described in this chapter.

Lorraine Aviation Motors.—The Societe Lorraine, 200 Route De Bezons, Argenteuil, S. and O., France, has produced numerous types of aircraft engines, both air- and water-cooled. The 100/100 C.V. Type shown at Fig. 641 is a five cylinder static radial type. The magnetos, oil pump and valve gear are placed at the propeller end of the engine. The carburetor, fuel pump, starting distributor and tachometer drive are located at the anti-propeller end as shown at Fig. 642. The compression ratio is five to one. The bore is 125 millimeters, the stroke is 140 millimeters which gives a stroke-bore ratio of 1.12. The cylinder is provided with one intake and one exhaust valve. The rated power of 100 CV (cheval-vapeur or French rating) is attained at 1,350 r.p.m. The total weight of the engine with accessories is 150 kilograms or 330 pounds, the weight-power ratio being 3.3 pounds per French horsepower.

The cylinders are made in two parts, the head is aluminum alloy and the barrel of steel, each being provided with heat radiating flanges as shown at Fig. 643. The valve seats are of special metal inserted in the alloy head. The cylinder retention is by clamping rings which hold it on the crankcase. Each cylinder is provided with two sparkplugs and a coupling for the air starter. The crankcase is a well ribbed aluminum casting, the ribs being inside and a large opening, closed by a plate, which also acts as a bearing support at the rear, permits assembly of the crankshaft and connecting rod assembly. The front section is removable and is provided to hold the timing and the magneto and oil pump drive. The rear cover of the crankcase also serves as a collector for the intake gas and pipes radiate from the chamber to the various cylinders in the conventional manner. This also carries various minor accessory drives. The pistons, which are

shown at Fig. 644 are of special aluminum alloy and are provided with two compression rings and one oil regulating ring, all being carried above the wristpin. The piston wall is relieved at the wristpin, which is retained by spring rings fitting annular grooves in the bosses.

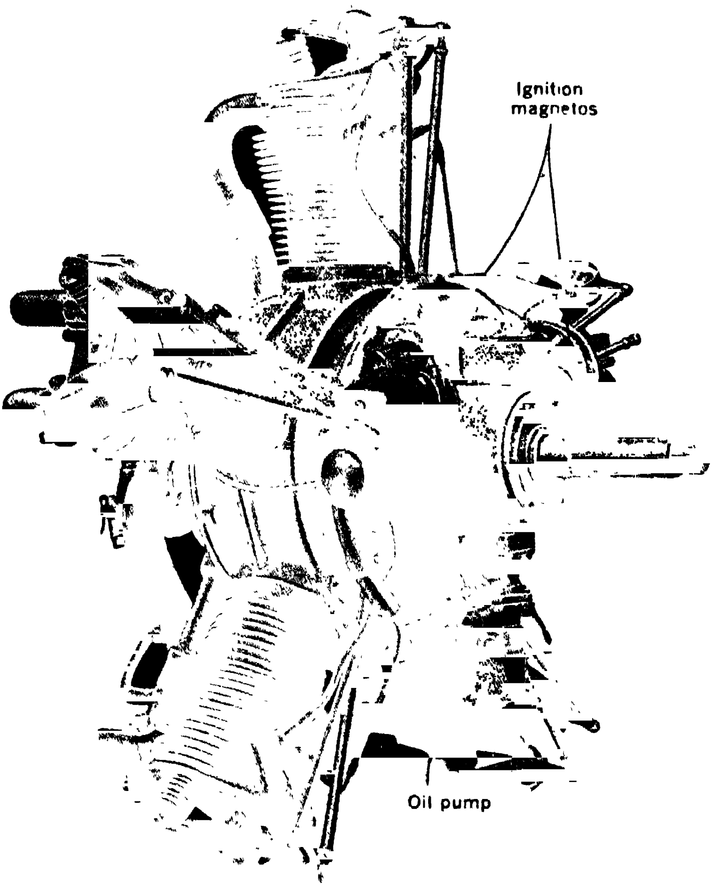


Fig. 641.—Three-Quarter Front View of Five-Cylinder Radial Lorraine 100/110 CV Engine.

The crankshaft, which is made of high strength alloy steel is a one piece forging carefully machined and balanced It is supported by two roller bearings and has counterweights bolted on. A ball thrust bearing supports the propeller hub end of the shaft. The shaft is bored out to secure lightness and passages for the lubricating oil. The connecting rod assembly is shown in place on the crankshaft at Fig. 645. The master rod is a steel forging of I section carrying link rods of tubular section. The big end

of the master rod is divided to permit assembly on the one piece shaft, the cap being held in place by four bolts. The link rods are bushed with bronze at each wristpin and knuckle pin bearing, the master rod big end is bushed with white metal.

The valve timing is by an epicycloidal or planetary gear train as shown at Fig. 646. The cam has two sets of lobes, one for the exhaust and one

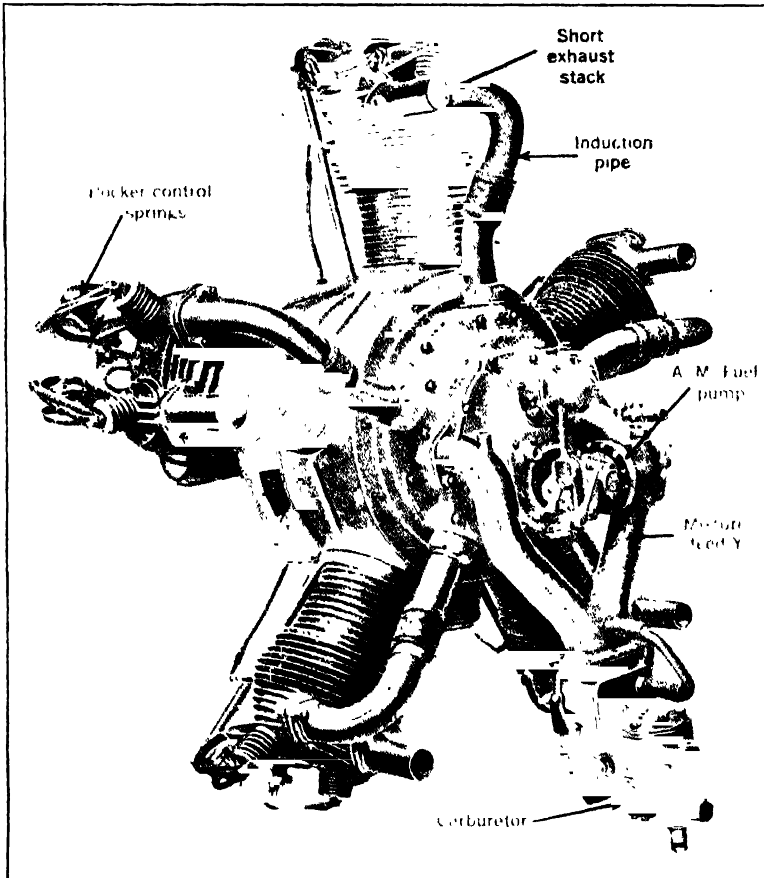


Fig. 642.—Anti-Propeller End of the Lorraine 100/110 CV Aviation Engine Showing Fuel Pump and Carburetor Installation.

for the inlet valves. The usual rocker arm and tappet rod valve actuation means is used. The valve rockers are mounted on roller bearings and have looped or horseshoe type return springs of flat steel which always keep rocker arm pressed against valve tappet rod ends. The oil pump comprises pressure and scavenging members and filtered oil is directed to the crank shaft interior, from which it lubricates the bearings and big end of master rod by direct pressure and the cylinder interiors by oil spray. Part of the

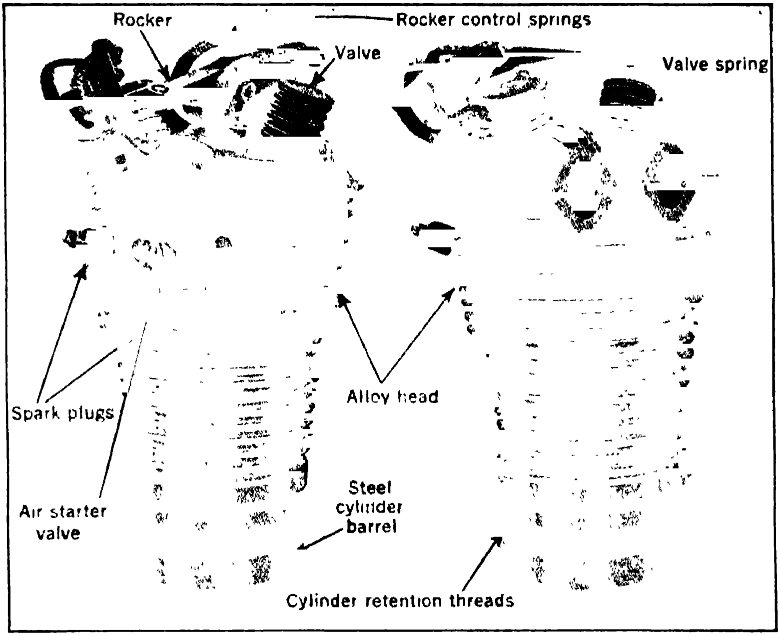


Fig. 643.—Lorraine Air-Cooled Motor Cylinder Construction.

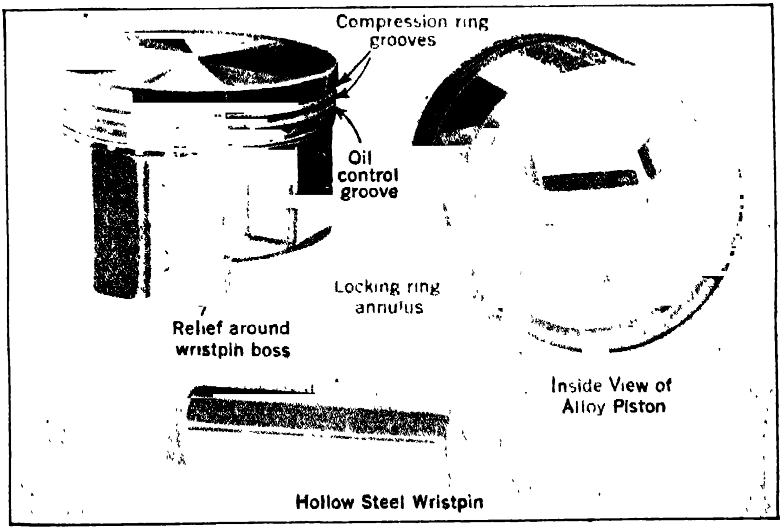


Fig. 644.—Lorraine Aviation Engine Piston is of Aluminum Alloy. Note Relief Around Wristpin Bosses.

oil is circulated around the mixture passage to heat the gas and simultaneously cool the oil. A double carburetor is used, provided with altitude correction means. Ignition is by two magnetos. A carbureted air starter is used, each cylinder being provided with a check valve fitting mounted between the sparkplugs. The Lorraine 230 C.V. motor is shown at Fig. 647 A This is a seven cylinder static radial type. It differs from the engine previously described in several important particulars. The magnetos, oil pump, double carburetor, fuel pump, starter distributor, gun drive and

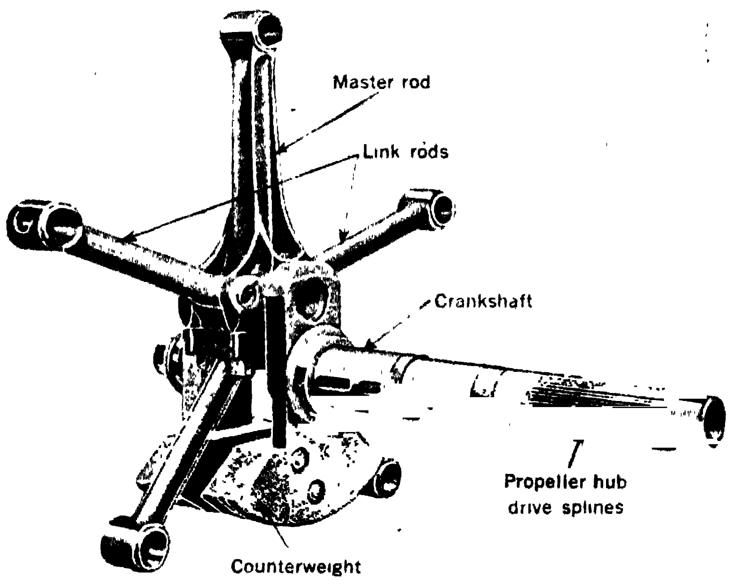


Fig. 645.—Crankshaft and Connecting Rod Group of Lorraine 100/110 CV Aviation Motor.

tachometer drive are all at the anti-propeller end, only the valve gearing being at the propeller end. The cylinder bore of this motor is 135 millimeters and the stroke 150 millimeters, the ratio being about the same as in the smaller motor. The cylinders are of composite construction, having one inlet and one exhaust valve in each cylinder. They are held to the crankcase by studs and nuts instead of threaded ring nuts as the smaller cylinders are. This engine delivers 230 C.V. at 1,800 r.p.m. The motor weighs 260 kilograms with propeller hub and 270 kilograms with all accessories.

A larger Lorraine engine having fourteen cylinders is shown at Fig. 647 B. It is composed of two banks of seven in staggered relationship The arrangement of accessory drives and valve timing and actuating mechanism is similar to that previously described. Its nominal rating is 470 C.V. at 1,800 r.p.m. but it has shown as high as 550 C.V. in tests with

higher compression cylinders. The normal ratio is five to one. The cylinders are the same as used on the seven cylinder engine and have the same bore and stroke. The engine weighs 420 kilograms with propeller hub and 440 kilograms with all accessories. Other models of Lorraine air-cooled engines are made but the forms illustrated may be considered typical.

Wright "Tornado" V1456 Engine.—The Wright "Tornado" V1456 is an experimental twelve cylinder air-cooled engine of the inverted "Vee" type, rated at 550 horsepower at 2,400 r p m. This type of high speed

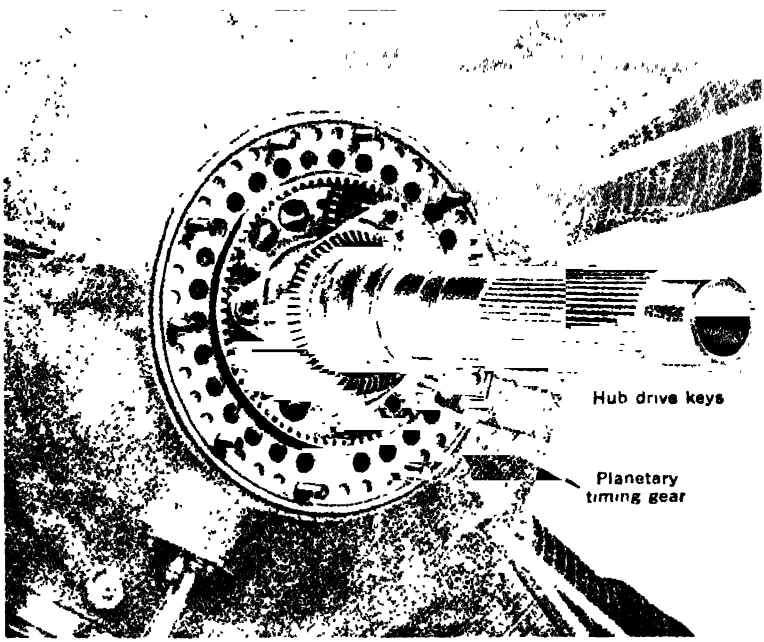


Fig. 646.—Planetary Valve Cam Drive Gearing of Lorraine 100/110 CV Aviation Motor.

engine is considered a very interesting development on account of its advantages for use in high-speed planes, especially combat planes. It is believed that this engine is the logical type to supplant water-cooled "Vee" type engines in medium and large sizes, such as the Wright "Tornado" T3 type which has served the United States Navy so well in the past few years. This engine has been previously illustrated at Fig. 231. As this is a special type but little data is available for publication at this time.

SPECIFICATIONS

Type ....Inverted Vee Air Cooled
Number of Cylinders . .. .12
Bore ....$4\frac{7}{8}$"
Stroke ....$6\frac{1}{2}$"
Rated Power ....550 b.hp at 2400 r.p.m.

Cameron Fixed Radial Type Aero Engine.—The Cameron engine of seven cylinders of fixed radial type air cooled has been built by the National Aero Corporation, of New York City, from designs of E. S. Cameron, who for a good many years was active in the automobile industry. The engine which is shown at Figs. 648 A, B, C and D, has a bore of 4⅛ inches, and a stroke of 4½ inches, giving it a displacement of 420 cubic inches. It is said to develop 100 horsepower at 1,800 r.p.m. and, weighing 280 pounds complete, its specific output is one horsepower for every 2.8 pounds of dry weight, and one horsepower for every 4.2 cubic inches of displacement

Fig. 647A.—The Seven-Cylinder Lorraine 230/270 CV Radial Air-Cooled Aviation Engine.

It is planned to build the engine with two different compression ratios, a ratio of 5.4 to 1 for installations where ordinary commercial fuels may have to be used, and a ratio of six to one where only aviation gasoline is to be used.

The crankcase, as can be seen by study of the sectional drawing at Fig. 648 A, consists of an aluminum casting, with an opening at one end through which the crankshaft can be introduced. This opening is closed by a cover plate, and the two anti friction roller type main bearings for the crankshaft are mounted in the end wall of the crankcase and in the cover plate respectively. High tensile cast iron alloyed with nickel and chromium is used

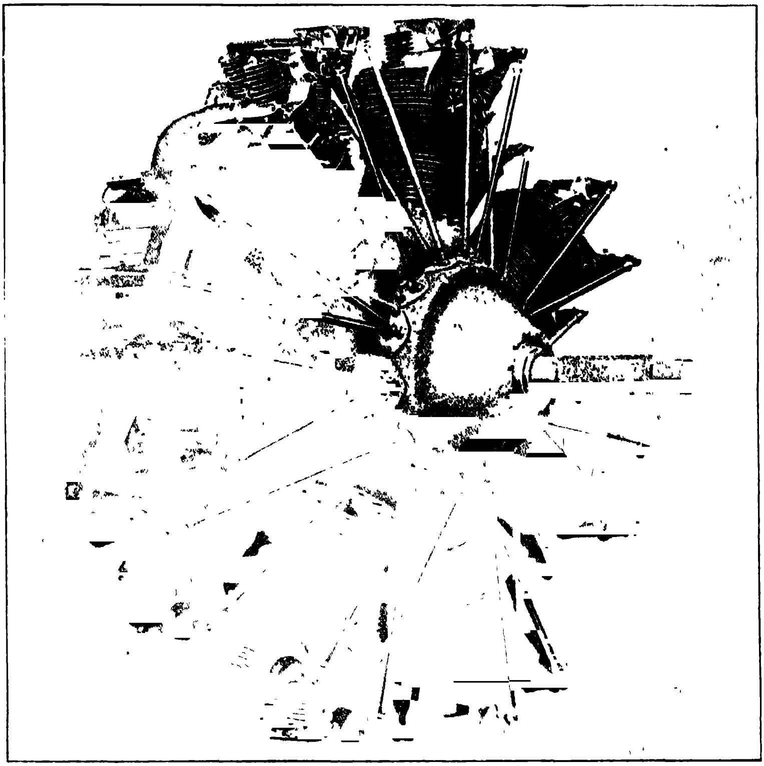


Fig. 647B.—The Fourteen-Cylinder Lorraine 470/550 CV Radial Air-Cooled Aviation Engine.

for the cylinder castings which have the cylinder heads cast integral with them. The cooling fins which increase in depth as the head is approached, are finished by machining except for one or two nearest the head, in the case of which there are necessary irregularities which make a turning operation impossible. Each cylinder is secured to the crankcase by means of an integral flange and a threaded ring, which makes a very light and secure fastening.

A feature of this engine is the arrangement of its valves and the form of its combustion-chamber. There are two inlet and two exhaust valves per cylinder. The two pair of valves are located opposite each other in the cylinder head, the exhaust valves having their seats directly on the cast iron of the cylinder casting, and the inlet valve having bronze seats inserted in

an aluminum inlet manifold which is held to the cylinder head by four studs. The stems of all four valves are parallel to the plane through the cylinder axes, so that the valve springs are located between adjacent cylinders. This gives a comparatively flat cylinder head which can be readily cooled by means of cast-on ribs or flanges extending in the direction of flight. Two sparkplugs are provided for each cylinder, at opposite ends of the compression chamber, and the incoming cool charge first fans the exposed inner ends of the sparkplug and then sweeps over the exhaust valve heads, all of which helps in preventing trouble from self-ignition and detonation.

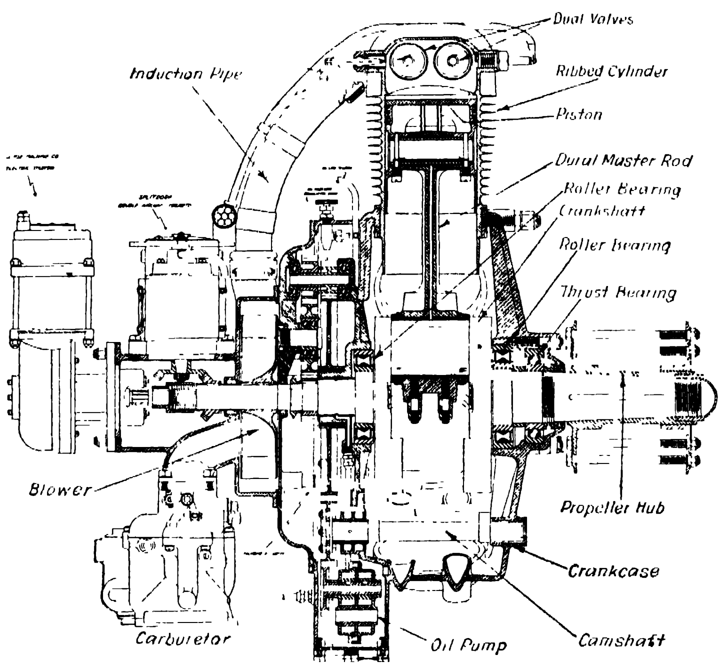


Fig. 648A.—Sectional View of Cameron Seven-Cylinder Air-Cooled Static Radial Aviation Engine Rated at 100 Horsepower at 1,800 R.P.M.

The valve operating mechanism, also, is out of the ordinary. In a housing at the forward side of the crankcase is arranged the timing gear, which comprises a cam gear pinion on the crankshaft, a number of small idler gears and a large idler gear mounted freely on the hub of the crankcase cover plate and meshing with gears on seven camshafts, one for each cylinder. Of course the gearing is so proportioned that each camshaft makes one revolution to every two of the crankshaft. Each camshaft carries one inlet and one exhaust cam and through these cams acts on rocker shafts which extend parallel with the cylinders up to the valves. The rocker

shafts at their outer end are provided with arms, but these do not actuate the valves directly. Intermediate shoes or sliding members of light alloy are used which protect the valves against all side thrust and thus minimize the wear of the valve stem guides. The intermediate member is a duralumin forging and slides on a hollow, hardened and ground steel pin. The hole in

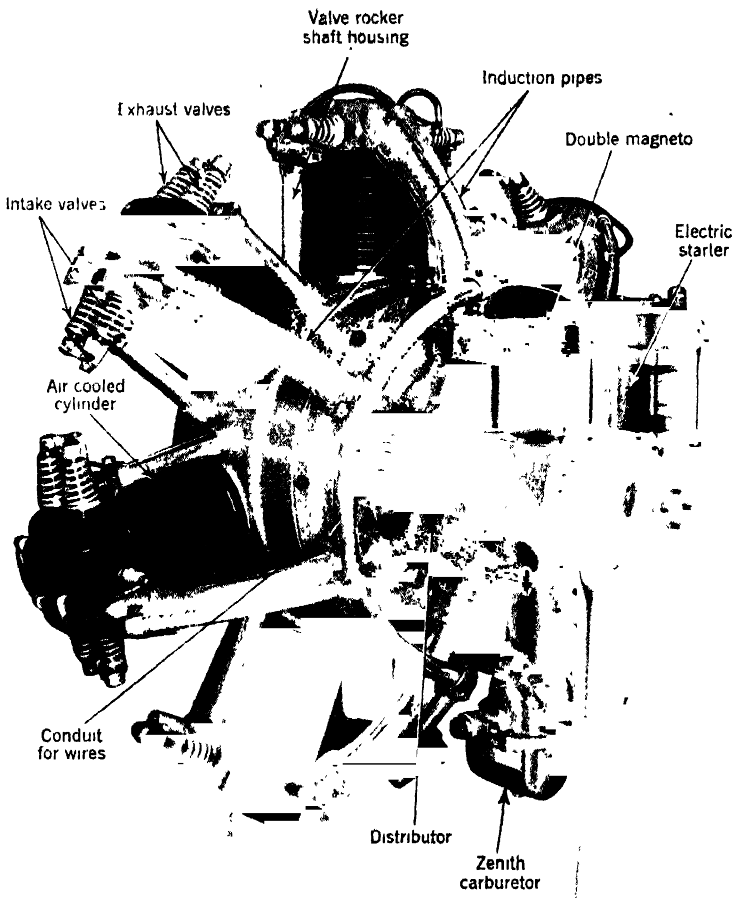


Fig. 648B.—Three-Quarter View of Anti-Propeller End of the Cameron Seven-Cylinder Radial Engine Showing Distinctive Valve Placing and Location of Ignition Distributors, Double Magneto and Starting Motor.

the pin is closed by a machine screw at the end and the pin is filled with graphite grease. This grease feeds out through a radial hole to both the sliding surface and a roller carried by the sliding piece and on which the lever arm on the rocker shafts acts.

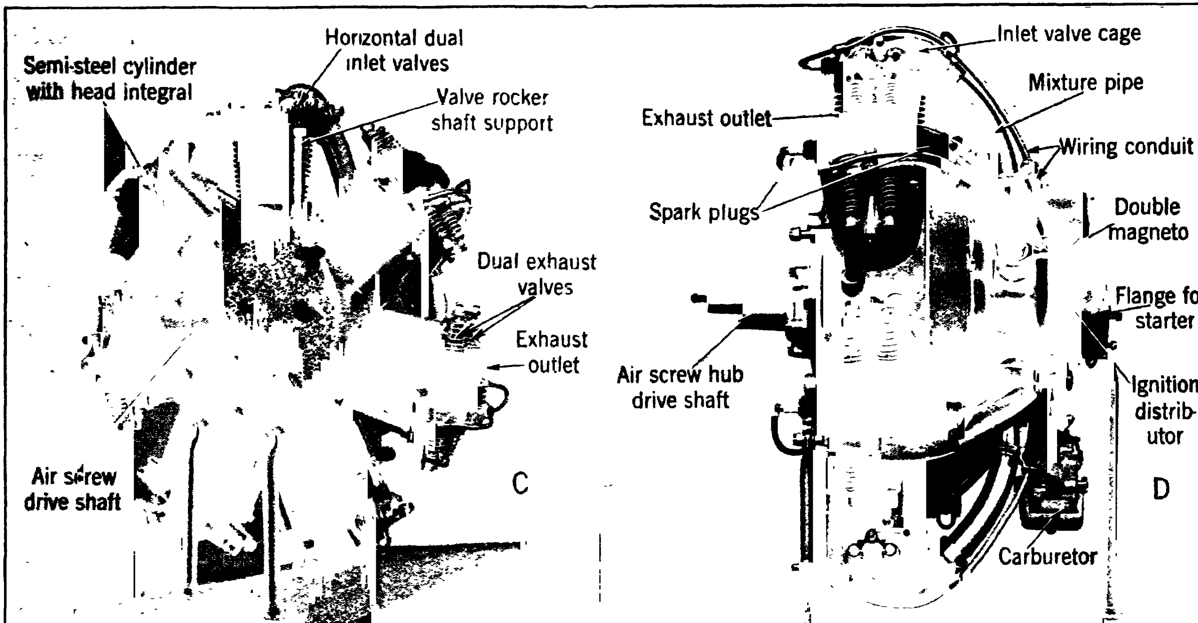


Fig. 648. C and D.—Front and Side Views of Cameron Seven-Cylinder Static Radial Air-Cooled Engine which Uses Distinctive Cylinder Construction and Valve Actuation Mechanism.

All the four valves have a clear diameter of 1¾ inches but the lifts are different, the inlet valves having a lift of 5/16 inch and the exhausts of ⅜ inch. Operation of the exhaust valves is through the same source of mechanism as that of the inlet valves.

The combustible charge for the engine is prepared by a Zenith carburetor of 1¾ inch size. This feeds through a vertical outlet to the chamber of a blower located in front of the timing gear housing. This blower is of the centrifugal type and serves to mildly supercharge the cylinders. The chief object of the blower is to insure a thorough intermixing of the fuel and air and consequently more uniform mixture distribution. The inlet to the blower from the carburetor is near the center and there are seven radial outlets from the blower housing, one to each of the inlet manifolds. These

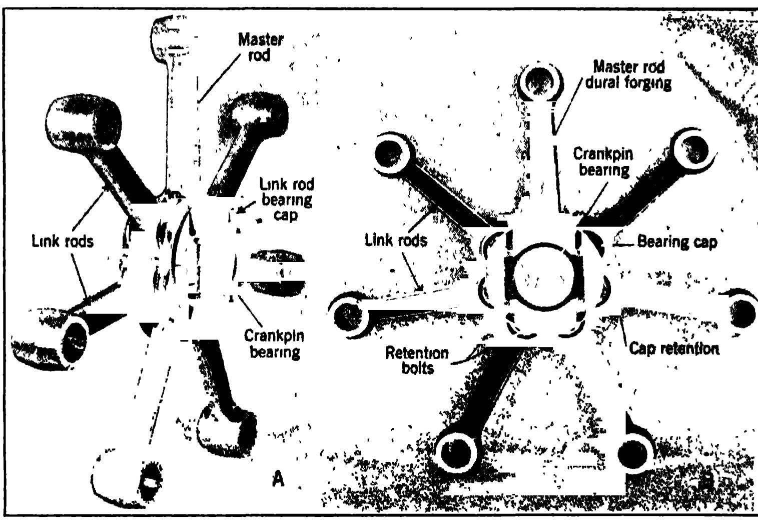


Fig. 649.—Master and Link Rod Assembly of the Cameron Engine is Made of Heat Treated Dural Forgings and is a Distinctive Design.

connections between the blower and the inlet manifolds are by duralumin tubes which are connected at their inner end by means of a gland nut and packing and at the inlet manifold end by means of a cap over the flange end of the tube. As in all engines of this type, the crankshaft has only a single throw and is provided with counterweights for balancing purposes. It is made of a high-carbon chrome-nickel steel forging. Radial loads on the crankshaft are taken up by the two main bearings which are Hoffman roller bearings, while all thrust load due to the propeller, etc., is taken up on a deep groove ball bearing at the propeller end. Pistons are cast of aluminum alloy and are fitted with four rings each. Piston pins are secured in the piston bosses by a pin-type set screw in each of the bosses.

While the usual arrangement of one master connecting rod and articulated smaller rods is employed, the connection of the articulated rods to the master rods is worked out in a novel way. All connecting rods are duralumin forgings, the complete assembly being shown at Fig. 649 A and B.

The master rod which has a center-to-center length of nine inches has a very liberal bearing on the crankpin—2½ by 3½ inches. The articulated rods are forged with the knuckle pin integral and this pin has a bearing in hardened and ground steel bushings in the master rod. Caps for the bearings of the articulated rods on the master rod are secured by means of studs screwed into the head of the master rod and headed over on the inside, so that it is not necessary to rely entirely on the holding power of

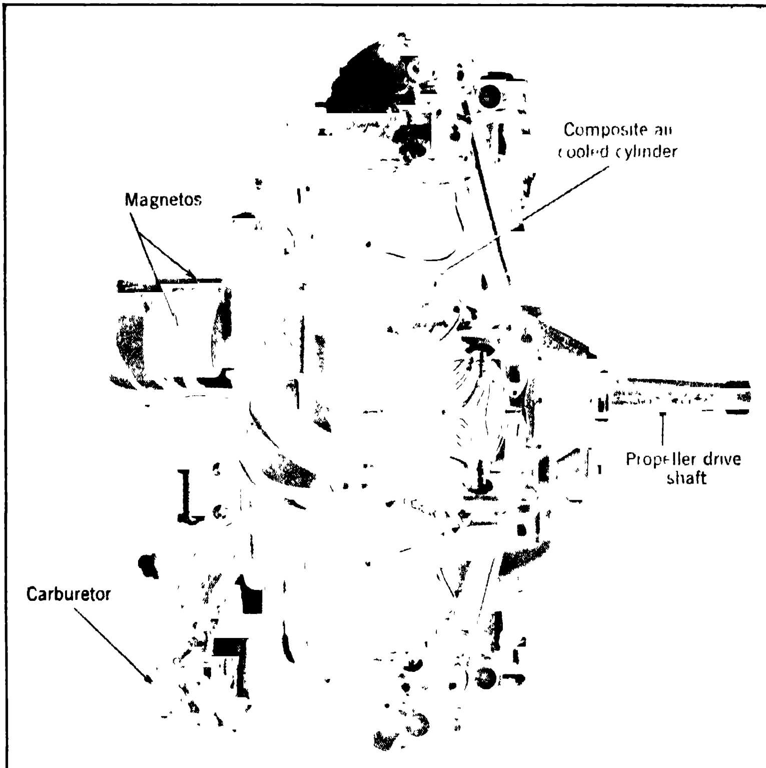


Fig. 650.—Side View of Curtiss "Challenger" Six-Cylinder Radial Air-Cooled Aviation Engine.

threads in the duralumin. This construction makes it possible to bring the bearings of the articulated rods closer to the crankpin axis. Each cap stud serves for two adjacent caps, except those nearest the master rod which anchor only one cap end instead of two.

Lubrication is by the dry sump system and the double gear-type pump, driven from the timing gears and located in a special compartment at the bottom of the crankcase. Oil enters the hollow crankshaft at a plain bearing adjacent to the roller bearing mounted in the cover plate and passes through the drilled-out connecting rod shank to the piston pin bearing and to the cylinder wall. All of the bearings of the articulated connecting rods

also are lubricated by the pressure system. The bearing of the master connecting rod on the crankpin is babbitted, the babbitt being poured directly into the head of the rod.

Ignition is by a Splitdorf double magneto which generates four double sparks per revolution of its armature. This magneto is installed on a bracket over the rear extension of the crankshaft and is driven from the crankshaft through bevel gearing at such a ratio that its armature makes 21 revolutions to 24 of the crankshaft as shown at Fig. 648 A. The armature generates four double sparks per revolution. It will generate 84 sparks for 24 crankshaft revolutions, which is the number required. Two separate

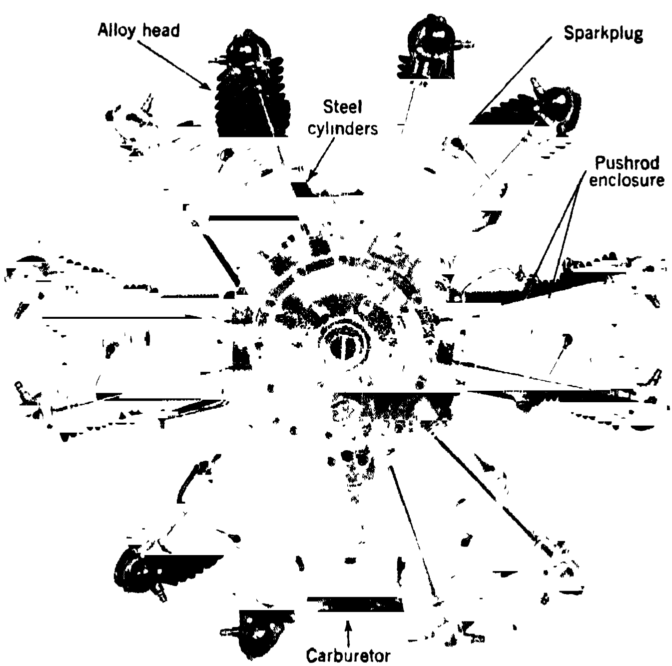


Fig. 651.—Front View of Curtiss "Challenger" Six-Cylinder Radial Air-Cooled Aviation Engine.

distributors are provided independent of the magneto for the sparks to each set of plugs and all high tension cables are carried inside a cable guard of duralumin tubing, even the wires from the plugs to the main cable guard are protected by oval section tubes securely fastened to the induction pipes.

Curtiss Challenger.—The Curtiss Aeroplane & Motor Company, Inc., long known as an outstanding manufacturer of military and commercial aircraft and engines, is now placing on the market its latest type of aircraft engine, the Curtiss Challenger. The Challenger is a six-cylinder air-cooled

radial type, developing 170 horsepower at 1,800 r.p.m. It has been produced primarily to fill the great demand for a reliable commercial engine of medium power. It is ideal in size for the two- or three-place open cockpit type of plane for training and general use, and for the increasingly popular small closed-cabin type. The Challenger differs somewhat in design from the usual single-row air-cooled engine. It has six cylinders, staggered in arrangement on a two-throw crankshaft as shown in the side view at Fig 650. This unique design provides several advantages over existing types The cylinder arrangement is equivalent to two three-cylinder engines mounted end to end. This provides for perfect dynamic balance, which is not possible with usual radial types, and makes the Challenger an exceptionally smooth-running engine throughout its entire operating range The staggered arrangement of cylinders makes possible excellent streamlining of the engine cowling. This, plus the inherently low frontal area of a short-

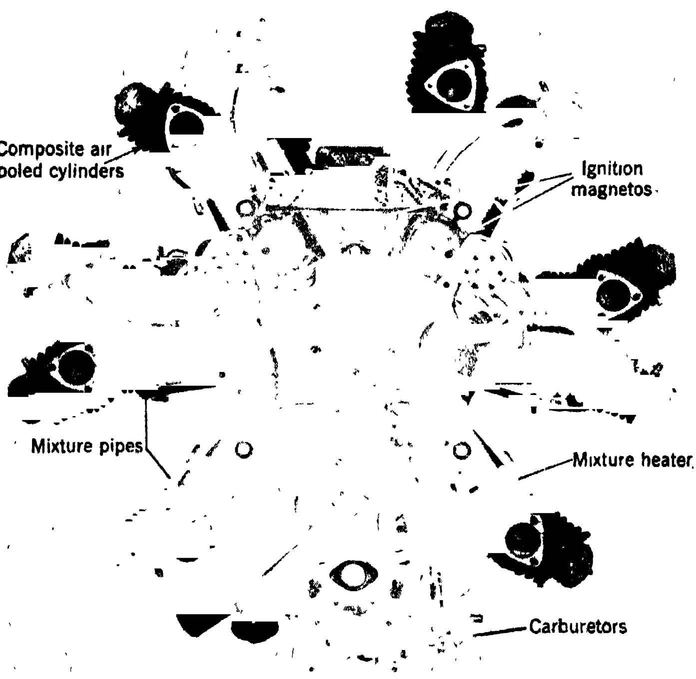


Fig. 652.—Rear View of Curtiss "Challenger" Engine Showing Mounting of Ignition Magnetos and Carburetor.

stroke, large-bore engine, insures excellent performance characteristics The front view of the Challenger engine is given at Fig. 651.

Perfect fuel distribution is obtained by the use of a double carburetor, each barrel of which supplies fuel to three cylinders through a simple manifold cast integral in the crankcase. These manifolds are of the closed or

"ramming" type, providing a surging, turbulent flow of gas to each cylinder, insuring maximum power. Excellent range of vision for the pilot is insured by the wide spacing of cylinders at 60 degrees and by the small overall diameter of the engine. Particular care has been paid throughout the design of the Challenger to the requirements of accessibility and easy maintenance. There is plenty of room to work on the engine, and the cylinders may be removed and the engine entirely overhauled without removal from the airplane. Adjustments on valve tappets, oil pressure, timing, and carburetor are easily made, and the carburetor and oil screens are accessibly located for periodic cleaning. The rear view of the Challenger engine at Fig. 652 shows the grouping of the accessories and auxiliaries. Recent flight tests of the Challenger engine in the Curtiss "Robin" cabin monoplane have thoroughly demonstrated its suitability for commercial service.

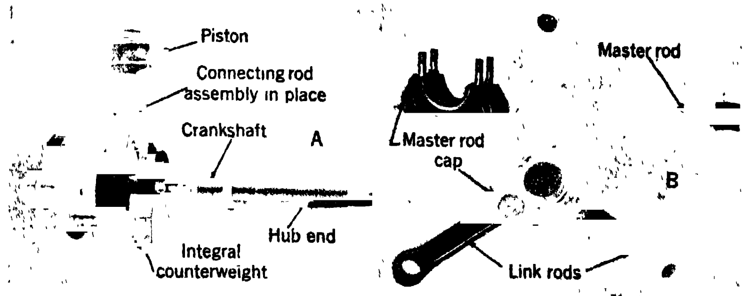


Fig. 653A.—Curtiss "Challenger" Engine Crankshaft and One of the Connecting Rod Assemblies in Place. B—Illustration Showing Construction of "Challenger" Master Rod and Link Rods.

The Robin, carrying a pilot, two passengers and baggage, takes off easily after a short run, climbs at 900 feet a minute, and has a top speed of better than 116 miles an hour. The first Challenger engine in addition to passing the standard 50-hour block test, has been flown for more than 100 hours under all kinds of flying conditions and so far has required no maintenance whatever.

The cylinders are the usual composite type having heat treated cast alloy heads screwed and shrunk on alloy steel barrels, flanges being machined on the barrels as well as cast on the heads. Rocker boxes are cast integral with the heads and are fitted with easily removable covers for valve tappet adjustment. Two valves are used per cylinder, these seating on the usual bronze insert. The ports for both intake and exhaust valves face directly aft, providing for simple manifolding. The crankcase in an aluminum casting in two halves, split through the center line of the front row of cylinders. This provides a rigid construction that permits of easy assembly. The induction manifolds, four bosses for mounting the engine and accessory drive housing are cast integrally with the rear half of the crankcase. Mounting bosses are provided with rubber inserts through which the mounting bolts pass and the absence of metal to metal contact eliminates or at least greatly reduces transmission of vibration.

The crankshaft which is shown at Fig. 653 A is a conventional two throw type in perfect balance, having small counterweights forged integral with the extreme crank cheeks. This conduces to smoother running and permits safe operation at high speeds. The crankshaft is mounted on three ball bearings, the one nearest the propeller hub serving as a combined radial

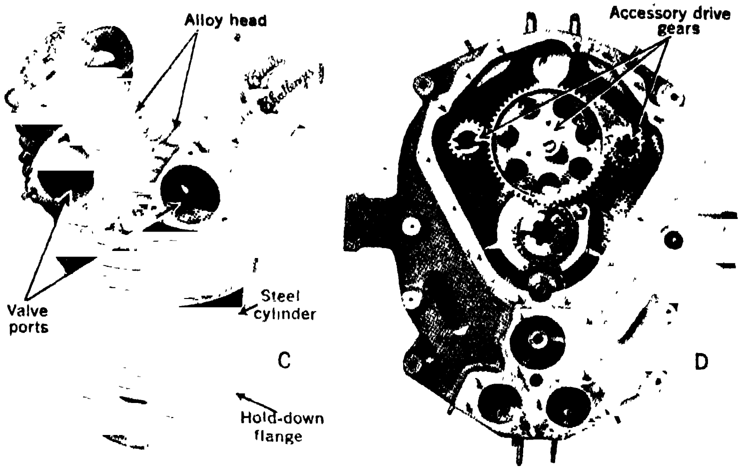


Fig. 653C.—The Curtiss "Challenger" Engine Cylinder. D—Accessory Drive Gear-case of "Challenger" Engine.

and thrust bearing. The connecting rods consist of two master rods, each fitted with two short rods. The master rods are positioned at 180 degrees to each other, providing against unbalanced inertia forces The master rod bearing cap is provided with four large studs for attaching it. This design provides a rigid cap with excellent support for the babbitt-lined steel-backed bearings. The bearings for the short rods are of bronze. All rods are heat-treated steel of "H" section and the assembly is clearly shown at Fig. 653 B.

The pistons are of cast aluminum alloy, of the regular Curtiss ribbed type, with domed heads. There is ample oil collection space within the piston to insure against oil running into the combustion-chamber, after the engine is stopped. Each piston is provided with five rings, two compression rings and two oil control rings being located above the piston pin, and a third oil control ring below it. Piston pins are full-floating, of case hardened alloy steel, and fitted with aluminum caps to protect cylinder walls from scoring. The valve mechanism is actuated by a double cam, driven through a train of four spur gears, eliminating the internal gears usually employed. Heavy duralumin push rods, with hardened steel ball ends, actuate the rocker arms, which are mounted in shielded ball bearings, and equipped with adjusting screws for valve tappet adjustment. These screws are carefully designed to reduce side thrust on the valve stems and increase

the life of the wearing parts. The valves are of special silchrome steel, seating on bronze inserts in the cylinder heads The excellence of the valve design is attested by the fact that after more than 200 hours of running in the first Challenger engine, the valves, without being ground, were found to still hold gasoline when tested.

All accessories are located on the rear of the crankcase, which they are protected from rain and dirt. The regular equipment includes two high-tension Scintilla Magnetos, and pressure and scavenging oil pumps Provision is made for standard types of starter, generator, and plunger type gun control. All accessories are driven through spur gears, which require no adjustment and thus reduce assembly and maintenance costs. The

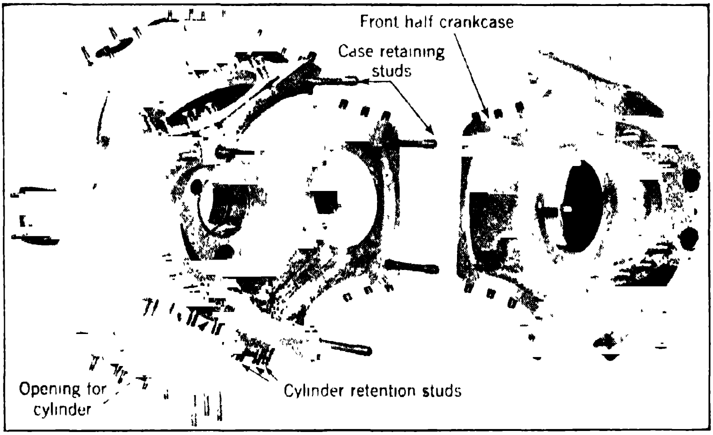


Fig. 653E.—Crank Case Construction of Curtiss "Challenger" engine, Showing Division Into Two Main Members.

lubrication system is the "pressure and scavenging" type, similar to that successfully employed in all Curtiss engines. A pressure pump feeds the oil tank through a fine screen in a small pressure chamber, to the rear main bearing, which is used as an oil seal. The screen is designed as a valve so that during cold weather if the oil is too thick to flow through the screen, it will lift from its seat and permit the oil to flow around it. The oil feeds into the crankshaft and the pressure is controlled at the propeller end by a bypass valve accessibly located in the nose casting. This method of control insures positive pressure to every point in the crankshaft, from which oil is distributed to all parts of the engine. The return oil collects in a sump at the bottom of the crankcase, so located that oil will drain into it at gliding attitudes. The pressure and scavenging screens, oil drain plug, and oil thermometer well are in this sump. A single scavenging pump removes oil from the sump and returns it to the oil tank. The rocker-arm bearings and ball ends are lubricated from Alemite connections on the rocker boxes.

The carburetor is a Stromberg NA-U4J double barrel type, simple in design and specially developed for use with the Challenger engine. Exten-

sive flight tests have demonstrated that the excellence of carburetor and induction system design provides the Challenger with remarkable acceleration from idling to full throttle speed, and smooth operation throughout the entire range. The carburetor is attached to the lower rear end of the crank-case for use with a gravity gasoline system. Provision is made on the engine for installation of an Army type O-5 fuel pump if it is desired to use a pressure fuel system. To insure perfect carburetion in cold weather the carburetor is exhaust jacketed around the barrels, using a hot-spot

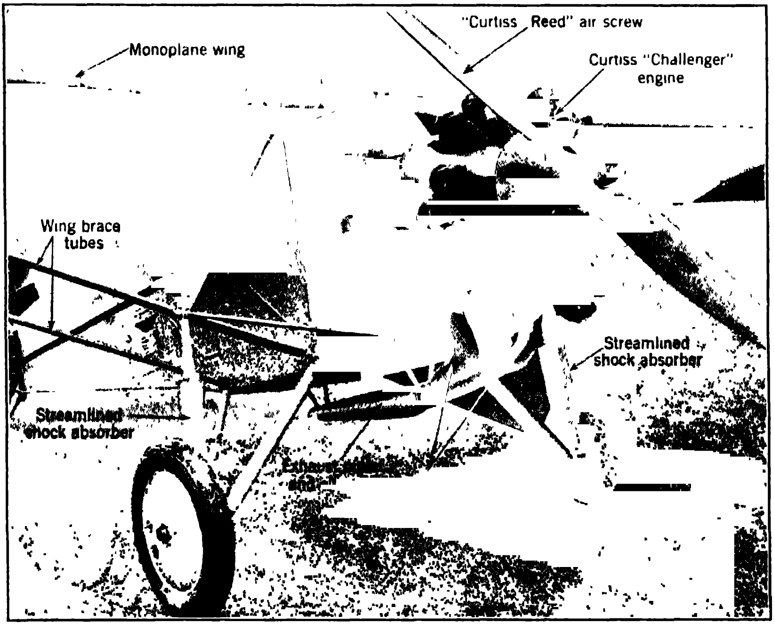


Fig. 654.—Front End of Curtiss "Robin" Cabin Monoplane Showing Neat Installation Possible with Curtiss "Challenger" Engine. Note Effective Cowling and Disposition of Exhaust Gases to Muffling Device Under Cabin.

elbow taking exhaust heat from the lower left cylinder. The hot-spot elbow is fitted with a valve to control the amount of exhaust heat admitted to the carburetor. This arrangement prevents the formation of ice in the carburetor and insures proper carburetion in any weather, without the loss of power caused by the usual type of auxiliary heater, which heats the air going to the carburetor. Dual ignition is provided by two six-cylinder high-tension Scintilla Magnetos located on the rear of the crankcase. There are two sparkplugs per cylinder, thus affording a reliable dual system of ignition. The magnetos are easily removed for overhaul.

CHARACTERISTICS

Name ....Curtiss Challenger
HP. (Rated) at 1800 R.P.M 170
Model R-600

Type of Engine	Static Air-cooled Radial
No. of Cylinders	6
Arrangement of Cylinders	2 Radial rows of 3
Bore	5⅛"
Stroke	4⅞"
Diameter of Engine (inches)	42⅝
Displacement	603 cu in
Ignition System	2 Scintilla Magnetos
Carburetor	Stromberg NA-U4J
Fuel Consumption Cruising	.50 lbs per B.HP. hour
Oil Consumption	.015 lbs per B.HP hour
Speed of Propeller	Crankshaft
Rotation of Propeller	Clockwise
Weight of Engine	420 lbs.

The Walter-Castor Engine.—The Walter Works, of Prague, Czechoslovakia, which already have gained considerable experience in the manufacture of air-cooled engines, have added to their line a 240 horsepower fixed radial type which was recently described in *Automotive Industries* and which is shown at Fig. 655. The engine was recently tested under the supervision of a committee of the Ministry of Public Works and passed successfully through the tests specified by the International Commission on Aerial Navigation. The cylinders are machined from a solid block of hammered steel and have the cooling fins and the flange at the lower end by which the cylinder is bolted to the crankcase turned during the machining process. At the top the cylinder is screw-threaded so the cylinder head can be screwed on. The cylinder heads are aluminum alloy castings, heat-treated. They are screwed onto the cylinders and locked in place by means of a device on which a patent has been applied for. The advantage of this construction is that the cylinder heads are readily interchangeable. Bronze valve seats are pressed into counterbores in the head and are rolled. The rocker levers have roller bearings on the rocker lever pins which latter are supported by pillars screwed into substantial bosses on the cylinder head. The valves are made of tungsten steel and their stems pass through removable bronze guides. Each valve is fitted with three helical springs.

The pistons are cast of aluminum alloy and have slightly concaved heads. Piston heads are re-enforced by ribs which also re-enforce the piston bosses. There are two compression rings on each piston, in addition to an oil ring. The master rod is made of chrome-nickel steel of I section and the articulated rods are of circular section. The master rod is supported on the crankshaft through two roller bearings. It is said that this construction has been fully proved out in other Walter engines and that, although the connecting rod head diameter is increased by the use of roller bearings, this enlargement is fully warranted by the long wear of these bearings. The connecting rod assembly is fully counterbalanced.

The crankcase is made in halves and also has two header plates. The halves are held together by steel bolts which also serve to fasten the engine down to the engine bearers of the plane. The crankshaft, which is a forging of Poldi steel, is supported on three roller bearings taking the radial loads due to gas pressure and inertia forces, and the third, a thrust bearing located in the front cover of the engine, taking the propeller thrust. The crankshaft

is made in two parts which are joined together by a method which is said to assure perfect rigidity. The crank arms are extended to the opposite side of the main journals and are provided with counterweights. A cam disc, which is located in the forward compartment of the crankcase, is provided with two series of cams, the four forward cams actuating the exhaust valves and the four rear cams the inlet valves. Each set of valves is actuated through pushrods with roller cam followers. The pushrods transmit the motion to the rocker levers which are fitted with helical retracting springs. The cam disc is driven from the crankshaft through a train of gears in an appropriate ratio.

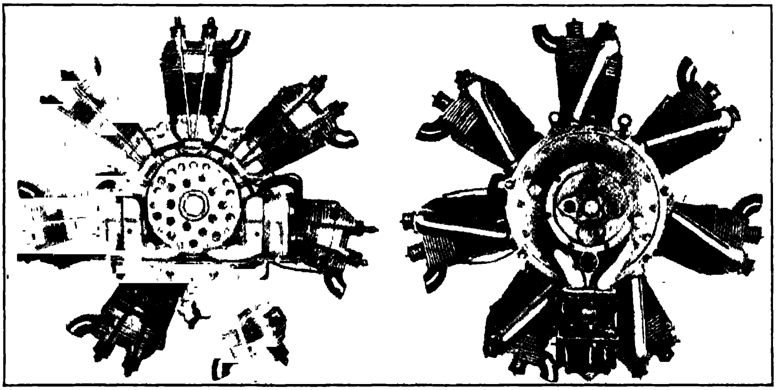


Fig. 655.—The Walter-Castor Seven-Cylinder Radial Aviation Engine.

A Zenith dual carburetor, Model 60 DCJ, is fitted to the rear cover and supplies mixture to a diffusing chamber formed between the end wall of the rear half of the crankcase and its cover. A rotor mounted on the crankshaft is located in this diffusing chamber and leads from the chamber extending to all of the inlet valves. The carburetor as well as the diffuser chamber is heated by oil from the engine. Lubrication of all parts of the engine is effected by means of a gear-type pump located in a cavity in the rear cover of the crankcase and driven from the crankshaft through a pair of spur gears. All of the oil draining from the various bearings collects in a sump communicating with the lowest part of the crankcase. The oil enters this sump through a strainer and is drawn from it and forced back to an outside oil tank by a drain pump, passing through the jackets of the carburetor and the diffuser chamber on its way.

Dual ignition is employed and two magnetos are fitted on brackets on the front case cover—either Bosch or Scintilla. The magnetos are driven by two gears from the cam disc drive. Auxiliary drives for the fuel pump, the distributor, the starter and the tachometer are inclosed in the rear cover which has a horizontal bottom. This method of mounting the accessories in the rear cover, where they are completely inclosed, assures absolute "cleanness" of the rear part of the engine. The drive for the generator is also mounted on the rear cover.

The Walter-Castor engine is designed for use on both military and commercial planes. The makers state that its high compression ratio permits of increasing its power by 100 horsepower over the normal rating at full throttle at ground level, and that this represents a reserve of 40 per cent of its rating for altitude work.

Following are the principal dimensions of the Walter-Castor engine:

Number of cylinders	Seven
Bore	5.314 in.
Stroke	6.693 in.
Compression ratio	6:1
Nominal output	240 hp.
Normal speed	1750 r.p.m.
Maximum output	260 hp
Maximum speed	1850 r.p.m.
Equivalent output	340 hp.
Consumption of a gasoline benzol 50-50 mixture of a spec. grav. of 0.800-0.810, per brake horsepower-hour	0.484-0.506 lb.
Consumption of oil per horsepower-hour	0.35-0.44 lb
Weight of engine with propeller hub	545 lb

Continental Seven-Cylinder Engine.—The engine is a fairly conventional air cooled seven-cylinder radial of split-crankshaft design. No attempt has been made in its design to achieve an unusually low specific weight or exceptionally high output per cubic inch of displacement, major attention having been given to a high safety factor for all parts, reliability of operation, ease of manufacture and reasonably low cost. The weight and output figures are well within commercial requirements, however, being 2.66 pounds per horsepower, and .276 horsepower per cubic inch (horsepower figures according to rating). The following description is taken from *Automotive Industries.*

The cylinders have a bore of 4 5/8 inches and a stroke of that length, giving a displacement of 77.7 cubic inches per cylinder, and 543 cubic inches for all seven. The compression ratio is five to one. At 1850 r.p.m., the engine develops 150 hp. The engine, with carburetor and magnetos but without starter, generator, exhaust pipes and air intake heater, weighs 400 pounds. Cylinder barrels are forged steel with aluminum alloy heads, heat treated, shrunk and screwed on. Valve rocker boxes are cast integral with the cylinder heads and are provided with cast aluminum covers, secured by studs and nuts. Aluminum bronze valve seats are shrunk into the head, spark plug inserts being of the same material.

Each cylinder is secured by ten studs and nuts to the cast, heat-treated aluminum alloy crankcase. The latter is split in the center plane of the cylinders, the front half carrying the ball thrust and main forward roller bearing. The rear half contains the rear main roller bearing, the cast-in induction manifold, cam follower guides, and mounting bosses. The main roller bearings are mounted in bronze liners, and the thrust bearing (which is located well forward of the front main bearing for crankshaft rigidity) in a steel retainer. A breather is located on the front crankcase half.

Pistons are of the long-skirt type and of heat-treated aluminum, being cast in permanent moulds. Piston heads are made fairly thick, to keep down the piston temperature and permit of small clearance without scuffing. Expansion reliefs are provided near the pin bosses. Piston pins are secured in the

pistons by wire snap rings. There are four rings to the piston, three above and one below the pin. Master and articulated rods are all of H section and of chrome vanadium steel, the master rod being of the one-piece type. All rods are completely machined. Link-pin as well as piston-pin bushings are of bronze, while the crankpin bearing is a steel-backed, babbitt-lined cylinder. Link pins are case-hardened and secured by locking plates.

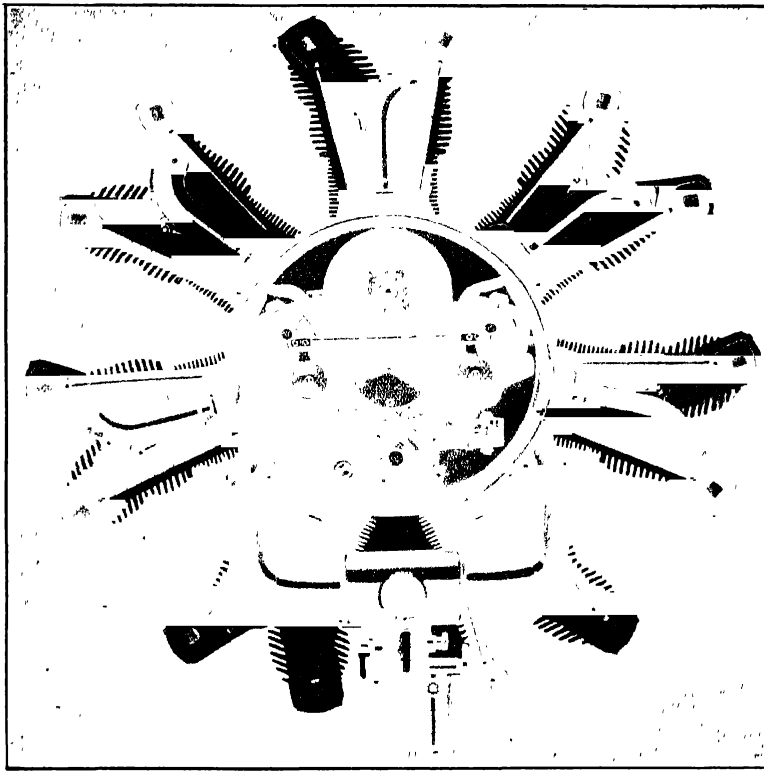


Fig. 655A.—Rear View of Continental Seven-Cylinder 150 Hp. Airplane Engine Showing Placing of Accessories.

The crankshaft is of the two-piece type, assembled at the rear crank-cheek It is of chrome-nickel steel. The two halves are secured by means of a clamping bolt. The shaft is drilled for lightness, and plugged to provide pressure lubrication to crank and link-pin bearings. Pressure lubrication is also supplied to accessory drive bearings, with splash to other parts. All oil leads are drilled, there being no internal oil piping.

Timing and starter gears are driven by a spline at the center of the rear portion of the crankshaft. The cam ring assembly is mounted on a bronze bearing and driven by an intermediate gear mounted on a stud shaft secured in the gearcase. The crankshaft starter gear mounted on the spline referred to meshes with the starter gear above the crankshaft in a one-to-one ratio. The

same crankshaft gear also meshes with the two magneto driveshaft gears, integral with these shafts. Cam and generator and pump shafts are driven by the crankshaft timing gear through a serrated clutch held in engagement by a screw at the end of the crankshaft. Of these shafts, the generator shaft is driven indirectly through the cam intermediate gear. The pump shaft is located transversely at the rear of the gearcase and is driven indirectly through helical gears on the generator shaft. From the pump shaft, which drives both a pressure pump and a scavenging pump, the tachometer and fuel pump drives are taken, one at each end.

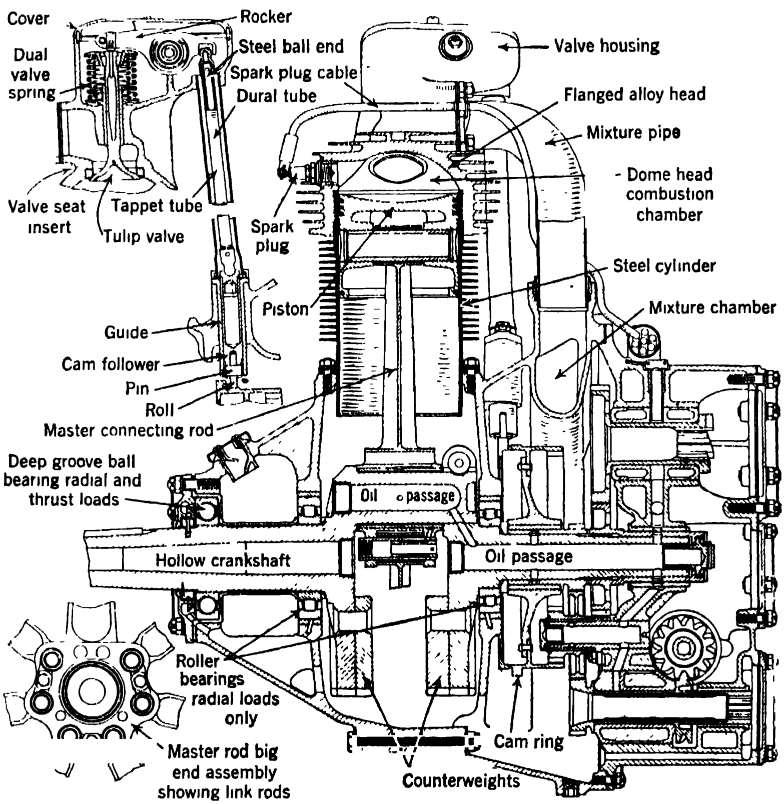


Fig. 655B.—Sectional View of Continental Seven-Cylinder Airplane Engine Through the Crankshaft Axis Showing Construction and Arrangement of Parts.

All accessory drive gears are forged integral with their shafts, and plain, split-type bearings are used, except in the case of the oil pump shaft, which is mounted on ball bearings. All these gears, except, of course, the helical pump gears, are of the straight spur stub-tooth type, and of chrome-vanadium steel. The serrated clutch mentioned above is for timing adjustment, which is easily accomplished by disengaging the clutch by loosening the screw at the rear end of the crankshaft.

Returning to the valve gear, cam follower guides are of a special aluminum alloy bearing metal. The cam ring and gear are of chrome-vanadium steel, case-hardened, and are riveted to a forged duralumin hub. Rollers are also case-hardened, as are roller pins and push rod cups. Push rods are of duralumin tubing mounted with hardened steel ball ends. Rocker arms are mounted on ball bearings, with tappet clearance adjustment on the front end of the rocker arm. Valves are of the hollow stem tulip type, both inlet and exhaust being made of CNS steel. Two straight helical springs are used on each valve.

Two Scintilla magnetos are fitted for ignition, the standard S.A.E. three-bolt flange mounting being used. Distributor units for battery ignition can be substituted. Sparkplugs are B.G., two per cylinder. Radio shielding can be furnished. Any type of starter now available, it is stated, can be mounted, since the starter shaft carries both a three-jaw clutch and an internal starter spline. Cylinder heads are tapped to accommodate the Heywood starter fittings. An S.A.E. flange is provided for a fuel pump mounting, to be driven through a coupling from the pump cross shaft. The carburetor is a single-barrel Stromberg. Mixture is carried to the cast-in, "horse-shoe" manifold by a double, U-shaped intake pipe. At the juncture of the arms of this pipe, an automobile-type hot spot jacket is provided. Heat control is designed to be operated from the cockpit by means of a butterfly valve, as in automobile practice. Exhaust flanges on the cylinders face forward. An exhaust ring and nose cowling will be furnished if desired, it is stated.

SPECIFICATIONS OF THE CONTINENTAL SEVEN-CYLINDER AIRCRAFT ENGINE

No. of Cylinders	7
Bore and stroke	$4\frac{5}{8}$ by $4\frac{5}{8}$
Displacement	544 cu. in.
Rated power	150 hp. at 1850 r.p.m.
Weight (approx.)	400 lb.
Fuel consumption	.52 per b.hp. per hr.
Oil consumption	.03 lb. per b.hp. per hr.
Diameter mounting bolt circle	20 in.
Outside diameter	$41\frac{3}{4}$ in.
Propeller mounting	S.A.E. No. 2 taper
Propeller mounting optional	S.A.E. No. 20 spline
Makers	Continental Motors Corp., Detroit, Mich.

Bristol Jupiter Engines.—One of the main features of the Bristol Jupiter engine is in the construction of the cylinders. They are turned from steel forgings, with the cooling flanges machined during the turning process, and have an integral combustion head provided with openings for the valve seats. To this cylinder an aluminum casting, having valve pockets in which are two sets of intake and exhaust gas ports, and forming a separate cylinder head, is applied in such a way that an intimate mechanical contact is obtained between the cylinder head and the integral steel combustion head to which the aluminum casting is secured. Each cylinder head is provided with two inlet and two exhaust valves. The seats of the valves form

separate units and serve an additional purpose by aiding to maintain contact between the steel cylinders and the aluminum head.

The pistons are of aluminum, and the connecting rods are arranged in the usual manner, in which eight link rods are pivoted around the big end of the master rod. An ingenious compensating device is provided to correct tappet clearance and compensate for the effects of the cylinder expansion due to rising temperature. The crankshaft is a two-piece member

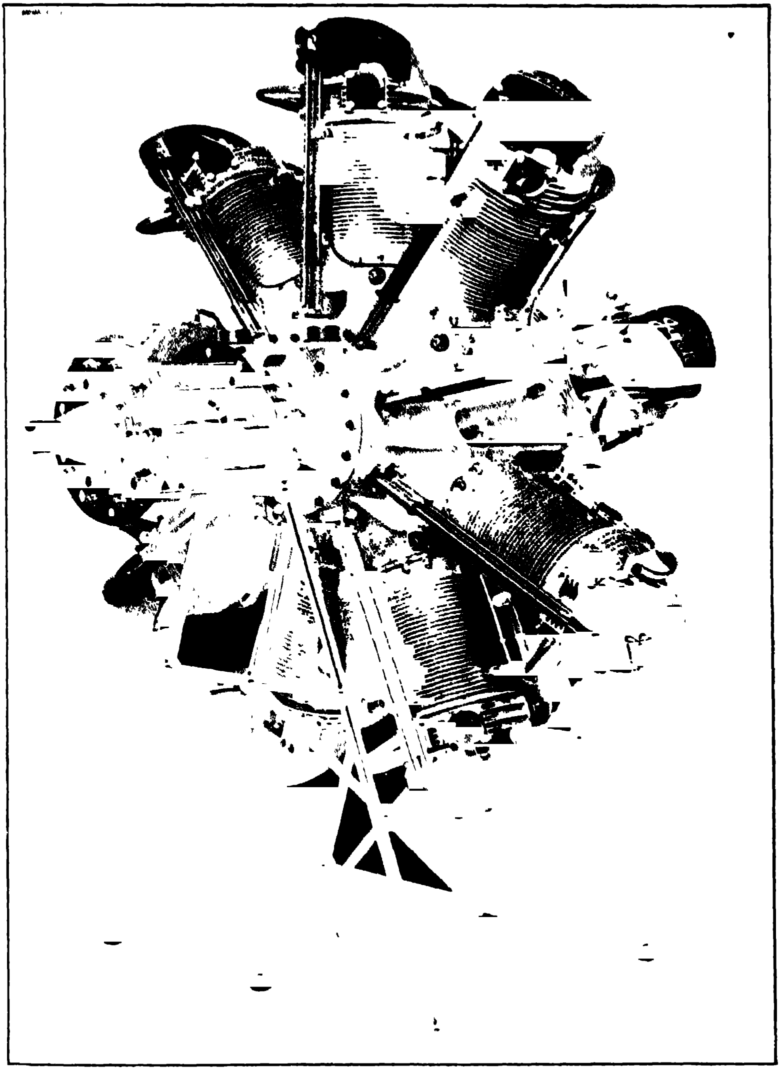


Fig. 656.—View from Propeller End of the Bristol Jupiter Series VIA, VIAM, VIAL Standard Ungeared Nine-Cylinder Radial Engine.

which has been previously illustrated and described. The crankcase is made of duralumin forgings instead of being a casting, which provides considerable increase in strength and some reduction in weight.

With the object of increasing the range of Jupiter engines the Bristol Company successfully carried out during 1927 an intensive development program in their Engine Experimental and Research Departments. In addition to the standard direct-driven type, the "Bristol" Jupiter is now available fitted with a gear-driven supercharger, or with a 2:1 reduction gear. The "Bristol" Jupiter Series VI A engine shown at Fig. 656 is a continuation of the well known Series VI, but with detailed improvements, by which the life is increased and upkeep is simplified, while its components are kept interchangeable with those of the supercharged and geared types, the whole series of Jupiter engines being generally interchangeable as regards installation Each of these engines has been granted a British Air Ministry Civil Type Test and accepted as airworthy under the Air Navigation Regulations and Directions Act. All types are now in production and are being fitted in the latest service and commercial aircraft. The "Bristol" Company, who are both aircraft and aero engine manufacturers, with the aero engine department adjacent to the aerodrome, have also developed and tested a complete range of installation extras and accessories for these engines, of which a complete stock is carried. Advice will be given on the most suitable types, so that customers can be relieved of the expense and delay usually involved with these accessories on new types of installations. The engines are made in various models as follows:

Jupiter VI.A., high altitude 6.3 to 1 compression: This engine is specially suitable for fast military machines with a normal operating altitude of 15,000 feet upwards. With standard British service 80/20 fuel the engine is run partially throttled at sea level, full throttle only being used at altitudes above 5,000 feet. At altitudes above this, the engine will show a considerable gain in power and fuel economy over the lower compression engines, giving the machine a proportionately higher ceiling.

Jupiter VI.A M., general service 5.3 to 1 compression: This engine is similar to the VI A., apart from the compression ratio. It is especially suitable for general purpose military machines normally operating at altitudes between 5,000 and 15,000 feet, and requiring the maximum power available at ground level with standard British service 80/20 fuel.

Jupiter VI.A L., commercial 5 to 1 compression: This differs from the VI.A engine in its compression ratio and the deletion of all purely military fittings. It is particularly suitable for commercial machines, the lower rating ensuring a very long life between overhauls and satisfactory operation over a wide range of conditions, and with standard aviation petrol.

Jupiter Series VII, high altitude, with gear driven supercharger: This engine is essentially for use with comparatively lightly-loaded service scout machines, normally operating at altitudes of 20,000 feet and upwards, and where the maximum performance at low altitude is not required. Full throttle is used only at altitudes of 12,000 to 15,000 feet upwards. Under these conditions the improvement in performance over the Series VI engine in identical machines is remarkable, being over 30 per cent in climb, 15 per cent in speed and 33 per cent in ceiling. This engine is interchangeable

with the Series VI, being only 40 pounds heavier in weight, and is intended for use with standard British service 80/20 fuel.

Jupiter Series VIII, geared two to one, high altitude, 5.8 to 1 compression: This is a development of the Series VI A. engine with the addition of a hand turning gear for starting purposes, an engine driven petrol pump, and a two to one reduction gear of the well known Farman bevel epicyclic

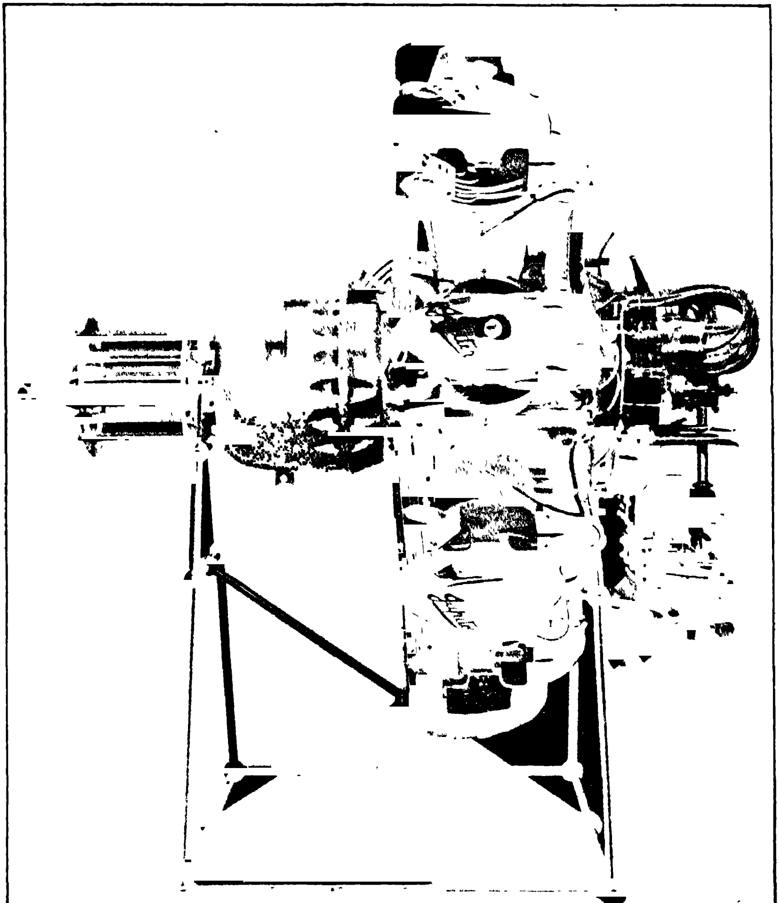


Fig. 657.—Side View of the Bristol Jupiter Series VIII, IX and XI Reduction Gear Engine.

type. The increased power output of this engine, combined with the high efficiency of the comparatively slow revolving propeller, make this engine which is shown at Fig. 657 and 658 particularly suitable for high performance bombers and comparatively heavily loaded service machines operating at altitudes of 10,000 feet upwards. With this class of machine the improvement over the Series VI engine is remarkable, being approximately

30 per cent on the climb, ten per cent on the speed and 30 per cent in ceiling The engine is run partially throttled at sea level, full throttle with standard British service 80/20 fuel being only permissible at altitudes of 4,000 feet upwards.

Jupiter Series IX, geared two to one, general service, 5.3 to 1 compression: This is the geared equivalent of the Series VI.A.M., for service where maximum power at ground level is essential, or where the operating height of the aircraft is below 10,000 feet. This engine is intended to operate on British standard service 80/20 fuel. Jupiter Series XI, geared two to one, commercial, five to one compression: The geared equivalent of the Series VI.A.L., for commercial use, or where the use of standard aviation fuel is required. Series VIII and IX engines can be supplied with engine-driven fuel pump, gas starter distributor, Hucks starter claw, hand-operated turning gear, and operating cams for Constantinesco gun gear. The Series XI accessories are similar to the above, but with an auxiliary drive running at twice engine speed, in place of the C C. gun gear and petrol pump.

The latest type of rocker gear standardized on all "Bristol" Jupiter engines from April, 1928, onwards incorporates several important modifications resulting in greatly reduced wear, combined with simpler maintenance. The use of ball bearings, in place of plain bearings, allows of grease being used instead of oil, giving a cleaner mechanism and approximately

THE "BRISTOL" JUPITER

Series VII

Leading Particulars

Type	9 cylinder air-cooled radial with gear-driven supercharger
Bore	5.75" 146 m/m
Stroke	7 5" 190 m/m
Total swept volume	1,753 cu ins. 29.7 liters
Compression ratio	5 3
Normal engine R P.M.	1,755
Maximum engine R P. M.	1,950
Engine rotates	Clockwise, looking on front
Propeller	Direct drive left-hand tractor
Rating at normal R P M.	420 B Hp. at 12,000 feet
Rating at maximum R.P M.	440 B Hp. at 15,000 feet
Rated boost	Minus 1¼ lbs /sq inch
Carburetor	I "Bristol" Triplex, oil heated
Ignition	Dual, 2 H.T. magnetos
Ignition control	Fixed
Oil system	Pressure 60 lbs. sq inch
Tachometer drive	¼ engine R.P.M
Fuel recommended	Standard service 80/20 benzol mixture
Oil recommended	Castrol R, or pure treated pharmaceutical castor
Standard weight bare	760 lbs.

This engine can be supplied with engine-driven petrol pump, gas starter distributor, Hucks starter claw, and operating cams for Constantinesco gun gear.

ten times as long between lubricating periods. The special ball-ended rocker adjusting screws give a greatly increased period between adjustments and ensure the retention of the correct clearances and valve timing on all cylinders.

The carburetor specially designed and supplied for this engine is the "Bristol" Triplex carburetor, consisting of three variable jet type carburetors, formed in one body and operated by one set of controls, giving a very compact instrument, which, while mounted low enough to allow of a good gravity feed, can be tucked up inside the cowling. The variable jet greatly facilitates tuning and gives an exceptional range of altitude control, as borne out by the results of official tests in high altitude scouts. The latest type now fitted to all Jupiter engines is heated by the hot oil drawn from the engine by the scavenge pump, the oil also circulating through the air intake elbow and the induction elbow, thus ensuring complete vaporization of the mixture, and preventing the possibility of the freezing up of the carburetor under adverse weather conditions. Additional heating is provided by the special forward type air intake drawing the carburetor intake air over the lower cylinders. For commercial machines, or where fuel economy cruising is of particular importance, the standard altitude control can be replaced by an automatic mixture control coming into action at any arranged throttle cruising position, and giving a ten per cent to fifteen per cent improvement in fuel consumption.

THE "BRISTOL" JUPITER

Series VIII, IX and XI

Leading Particulars

Type	9 cylinder air-cooled radial	
Bore	5 75″	146m/m.
Stroke	7 5″	190m/m
Total stroke volume	1,753 cu ins.	28 7 liters
Normal engine speed	2,000 R P.M.	
Maximum engine speed	2,200 R P.M.	
Propeller	Left hand tractor	
Propeller gear ratio	2 : 1	
Carburetor	1 "Bristol" Triplex, oil heated	
Ignition	2 H T magnetos	
Ignition control	Fixed	
Oil system	Pressure 60 lbs. sq. inch	
Tachometer drive	¼ engine R P M.	
Fuel recommended	Standard service 80/20 benzol mixture	
Oil recommended	Castrol R, or pure treated pharmaceutical castor	
Standard weight, bare	880 lbs.	

	Jupiter VIII	IX	XI
Compression ratio	5 8	5 3	5
Rated B.HP. at normal R P M.	440 at 4,000′	485	460
Rated B.HP. at maximum R.P.M	480 at 4,000′	525	500

An integral gear-driven supercharger is incorporated in this engine, in place of the spiral induction system, which is such a well proved feature of the naturally aspirated Jupiter engine. The blower is of the high speed centrifugal type, embodying certain interesting patented features, eliminating the inertia problems inherent with this type of mechanism. The system of slipping clutches employed ensures that the impeller is protected from shock loads, the torque in the blower drive being practically constant; this, combined with the low tooth loadings, gives a quiet running drive of exceptional durability. The unit is mounted immediately behind the rear wall of the crankcase, concentric with and driven from the tail end of the crankshaft, around which it revolves. In order to retain the simplicity and reliability of the standard type of carburetor and controls, the "Bristol" Triplex carburetor is mounted on the intake side of the blower, the mixture being drawn axially into the impeller and discharged radially via a fixed diffuser into the annular induction chamber, which replaces the induction spiral From this chamber the mixture is fed to the cylinders by nine radial pipes in the usual manner.

The fuel pump is of the well known gear wheel type, giving a nonfluctuating flow suitable for direct feed to the carburetor, and has been developed to meet the demand for a more efficient and reliable unit than the windmill type pump at present in general use. It is standardized on the Jupiter Series VII, VIII and IX engines, being positively driven from the gun gear drive shaft through a ball-ended vertical shaft enclosed in a telescopic tubular duralumin case, the pump being mounted on the induction elbow in a conveniently low position. All bearing surfaces are automatically lubricated by the fuel circulating through the pump, and leakage along the driving shaft is prevented by a spring loaded cork-packed gland. A relief valve, suitable for attachment in any convenient position, is also supplied, and is intended for use when the pump feeds the carburetors direct. It is of the spring loaded type set to a suitable pressure and bypassing all fuel in excess of the engine requirements, thus preventing flooding of the carburetor due to abnormal feed pressures.

For the benefit of aircraft constructors, it is the policy of the Bristol Company to develop, test and standardize for each type of engine a suitable exhaust system, which will act as an exhaust collector, flame damper and silencer. To simplify the installation the rings are entirely supported from the engine, and, in addition, provision is made for utilizing the exhaust ring as the front support for the engine cowling. The latest types evolved, as the result of extensive bench and flight tests, supersede all earlier types. The down pipes are kept within the cylinder outlines, in order to cut down head resistance, and afford the maximum possible fairway for gun fire, etc Deflector rings are provided to ensure a steady flow of air around the rear of the ring, preventing hot spots and stagnant areas, and, in conjunction with the special expansion joints, eliminate all fire risk. Special screwed spherical joints are provided to ensure a flame tight joint, combined with reasonable freedom for assembly purposes to ensure interchangeability of rings.

These rings have been type tested, and the detail design and dimensions are such that back pressure and consequent loss in brake-horsepower is negligible. The Fescolizing treatment given the exterior makes them pro-

against corrosion, from heat and atmospheric effects, with the result that the life of the rings is indefinite. At the present time these exhaust systems are available in two types, one suitable for all types of Jupiter VI engine installations, and one for all types of Jupiter VIII, IX and XI installations. For the supercharged Jupiter VII an exhaust system is not yet available, the engine operating with short exhaust snouts.

Bristol Reduction Gear.—The reduction gear incorporated in the Series VIII, IX and XI engines is the well-known Farman patented self-centralizing

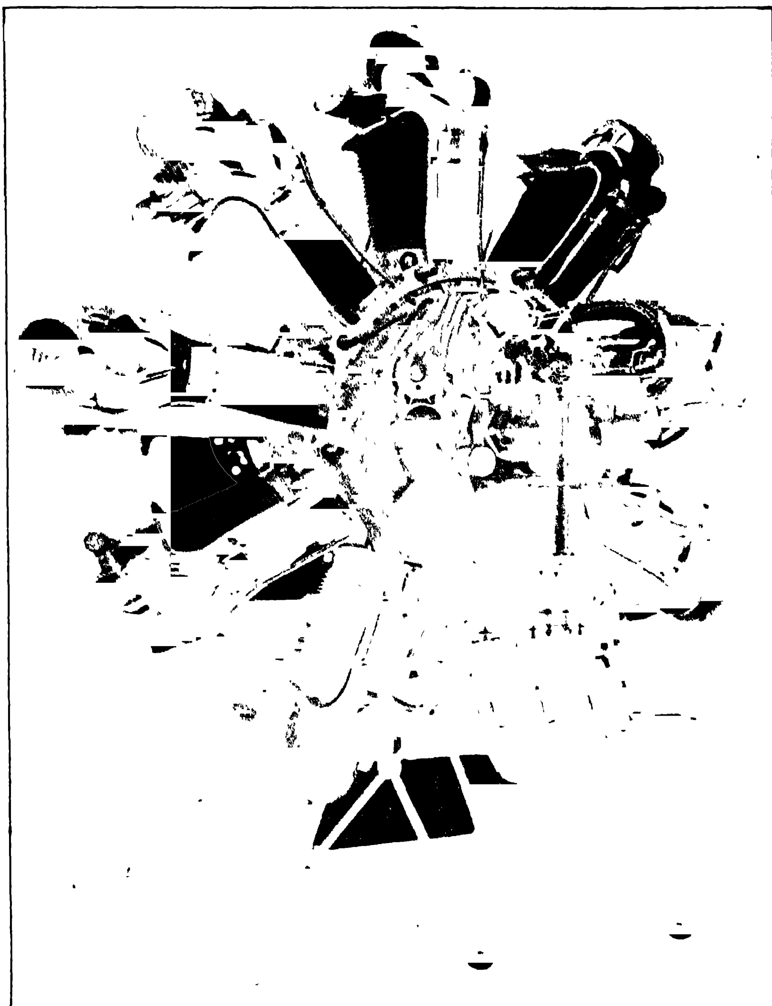


Fig. 658.—Rear View of the Bristol Jupiter Series VIII, IX and XI Reduction Gear Engine.

bevel epicyclic reduction gear, as developed by the "Bristol" Company for the Jupiter engine and shown at Fig. 660. This gear does not suffer from the drawbacks of abnormally high tooth and bearing loads, or an offset propeller shaft, customary with the conventional types of epicyclic or countershaft reduction gears. The special floating mounting ensures that under all conditions the driving gear adjusts itself to mesh with the three pinions and is centered solely by its engagement with them, with the result that the drive is equally distributed. All bearings are force lubricated from the engine lubrication system, while the thrust in the gear unit is entirely self contained, and no axial load is put on the crankshaft bearings. The whole gear is extremely compact and can be assembled as a complete unit remote from the engine; its efficiency is very high, and it is particularly quiet in operation.

A hand-operated engine turning gear has been included in the equipment of the geared Jupiters, as these engines are primarily intended for large single- and multi-engined machines where propeller swinging is impracticable, and where a reliable alternative method of engine starting must be available in case of the failure or absence of the auxiliary starter units usually employed. Provision on both port and starboard sides is made for operating handles, and with the reduction ratio employed of 30 to 1, even the stickiest engine can be comfortably turned at a suitable speed for starting purposes. The operating gear is engaged through a spring-loaded toggle movement, and is automatically thrown out of engagement, either when the engine fires normally or back fires, thus ensuring absolute safety for the operator. This movement has been subjected to a prolonged series of tests, with artificially produced back fires, and its efficiency demonstrated with complete success. The unit is connected with the engine lubrication system, generous-sized ball, journal and thrust bearings are used, and as the gear is out of engagement when the engine is running, wear is reduced to a minimum.

Jupiter Crankcase Construction.—The two halves of the crankcase are secured by nine bolts which serve both to register and secure the joint and also to support the engine on its plate. Near their rear ends these bolts have collars formed on them, sunk into recesses in the crankcase, behind the face of which the ends of the bolts project sufficiently to pass through the corresponding holes in the engine plate. The front half of the crankcase has two large concentric cylindrical projections going forward from the front wall, and providing accommodation for the eighteen tappet guides. The outer cylindrical casing is formed integral with the front half of the crankcase, while the inner is bolted to the wall and forms a housing for the cam gear. The rear half of the crankcase has formed in it an oval-section annular induction chamber, or rather part of such a chamber, the oval section being completed by a detachable cover. This chamber receives the three-start spiral which distributes the mixture to the nine cylinders, and which forms such a conspicuous feature in the design of the Bristol "Jupiters." Evenly spaced around the circumference of this annular induction chamber are nine circular apertures faced at their outer ends to receive the flanges of the nine induction pipes. In the lower sector of the rear cover for the spiral are three ports, also faced at their outer ends.

to receive the Bristol "Triplex" carburetor, which has been described in the chapter on Carburetors in Volume One.

The evenly spaced apertures for the nine cylinders are faced at their outer ends to receive the cylinder base flanges, which are secured to the crankcase by eight bolts each, four in each half of the crankcase. The location of these bolts will be seen in some of the illustrations. In the lowest part of the crankcase provision is made for the attachment of the oil sump, which is formed as a special unit. The construction of the important parts of the Jupiter engine may be understood by referring to Fig. 658 A.

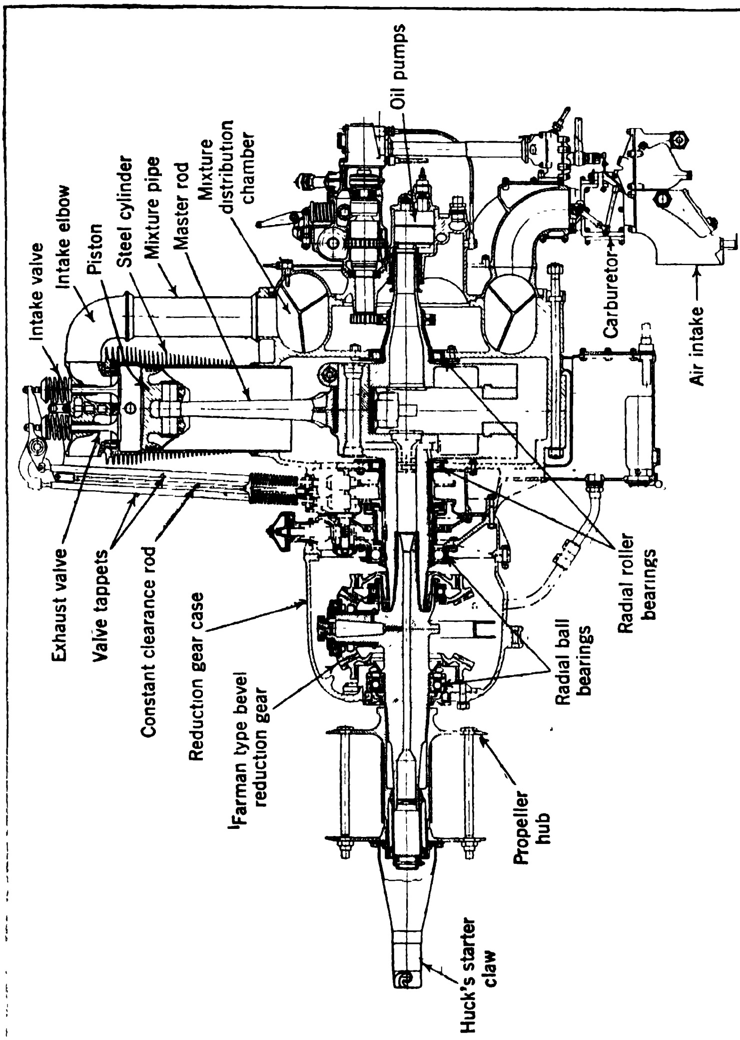


Fig. 658A.—Longitudinal Section View of Bristol-Jupiter VI Nine-Cylinder Aircraft Engine Showing Application of Farman Type Bevel Reduction Gear, Also Internal Construction of Engine.

Jupiter Cylinder Construction.—The cylinders of the Bristol "Jupiter" have steel barrels and aluminum alloy heads, a face joint being formed between the two, which are secured by eleven studs and four set screws. The cylinder barrel is machined from a steel forging, and has its crown formed integral with the cylinder, so that the valves seat direct in the crown, and there are no separate valve seats to work loose. Also, of course, the integral crown takes the explosion pressures.

The cooling fins, turned from the solid, are carefully proportioned to give even cooling, and it is of interest to note that they are formed eccentrically with reference to the cylinder barrel, being deeper at the back of the cylinder where the cooling is likely to be less effective. To give an idea of the care taken in the production of "Jupiter" cylinders it may be stated that the average weight of the steel forging from which the cylinder barrel is turned is 88 pounds, of which approximately 70 pounds is machined off, leaving the finished weight about eighteen pounds.

A short distance below the bottom fin the cylinder barrel has formed on it the base flange by which the cylinder is attached to the crankcase. The flange has two bolt holes at each of its four corners for the reception of the holding-down studs, of which, as previously mentioned, four are situated in the front half of the crankcase and four in the rear half. This construction is clearly shown in sectional view of the cylinder at Fig. 658 A.

The cylinder head, of aluminum alloy, contains the valve ports, and carries the valve mechanism, the topmost fin forming a bridge or platform which not only stiffens the casting, but also supports the valve guides and valve springs. Around the exhaust ports the cylinder head casting is generously finned to assist in dissipating the greater heat attained in this locality, and distance pieces of "Invar," a material the coefficient of expansion of which is negligible, are interposed between the nuts of the securing studs around the exhaust ports and the metal of the casting in order to maintain an even pressure by compensating for the difference in expansion of the aluminum head and the steel studs. The features of the valve action have been fully described in a preceding chapter.

In the case of the inlet valve ports, shallow recesses are cut in the steel crown and the head casting, to receive phosphor-bronze spigot rings, which serve to locate the head, and also to seal the inlet port joint. On each side of the cylinder head is formed a tapped boss for the reception of the sparking plugs, while a similar but smaller boss on the front of the cylinder head accommodates the non-return valve of the gas starter system. The gas passages for the four valves are so arranged that those for the inlet valves (at the back) face aft, with their axes parallel with the line of flight, while the exhaust valve passages are at right angles with each other, i.e., at an angle of 45 degrees to the center-line of the crankshaft.

Bristol Jupiter Oiling System.—The general lubrication system of the "Jupiter" is of the "dry sump" type, in which fresh oil is supplied under pressure from one pump, and, after passing through the engine is withdrawn by another known as the scavenger pump, and returned, via a cooler, to the tank. Certain parts are supplied with oil under direct pressure, while others are lubricated by splash. Oil is delivered under pressure to the cam gear, the big end of the master connecting rod, the magneto and oil pump drives, i.e.—gun gear

drive, and gas-starter distributor drive. Splash lubrication by the oil which has drained from the parts mentioned above is supplied to the pistons, small ends of the connecting rods, wrist pins of articulated rods, main crankshaft roller bearings and spherical roller bearing, and tappets and cam faces. The valves probably receive a certain amount of lubrication from oil that has passed the pistons.

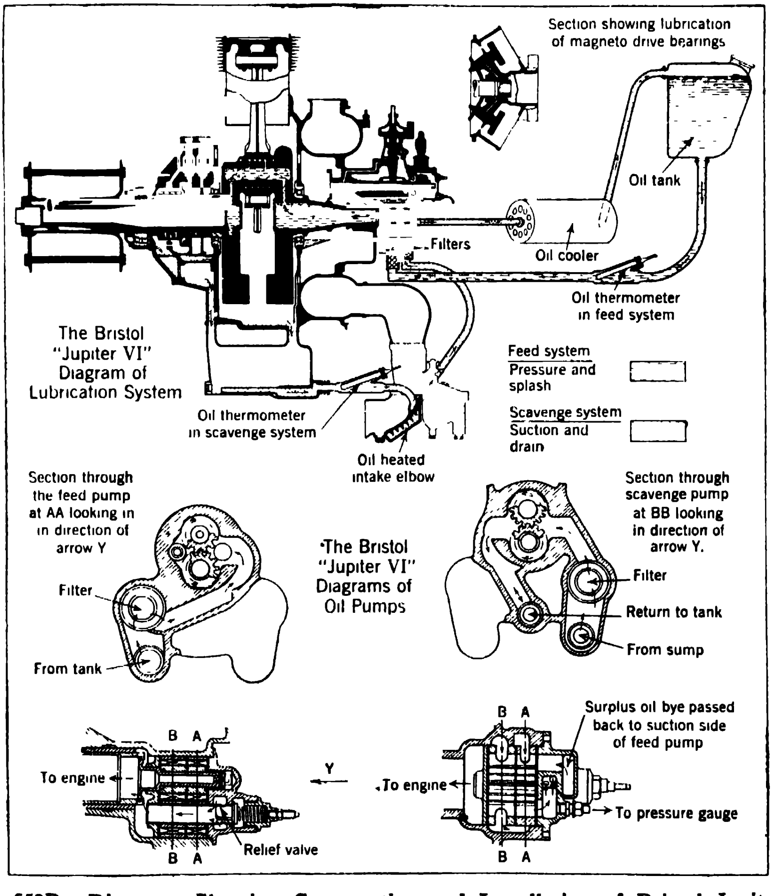


Fig. 658B.—Diagrams Showing Construction and Installation of Bristol Jupiter VI Lubrication System. Upper Diagram Shows Circulation of Oil. Lower Diagrams Outline Construction of Oil Pressure and Scavenging Pumps.

The scavenger pump (which has a capacity of approximately one-third greater than that of the pressure pump) collects oil from the sump unit at the bottom of the crankcase, and returns it by way of an oil cooler, to the main oil tank. From the oil tank the oil runs to the pressure pump under the force of gravity as shown at top of Fig. 658 B.

The oil delivered by the oil pressure pump into the hollow bore of the rear end of the crankshaft passes through the shaft bore to a duct drilled in the

rear web of the crank throw, and thence into the hollow crankpin. Tw(ducts are drilled radially through the crankpin wall, and their outer end· emerge on a flat formed on the outer face of the pin, the oil thus being admitte, to the inner surface of the floating bush, which is interposed between the crank pin and the master rod big end. A number of holes in the bush itself pass th oil to the outer surface of the floating bush, and thus to the big end of the maste rod. From the ends of the floating bush the oil emerges, and is splashed to the inner surface of the crankcase, cylinders, pistons and small ends, etc.

The main pressure supply leaves the inside of the crankpin through a duct in the front web, and this communicates with a broad shallow oilway formed on the front portion of the shaft. The components situated on the shaft (i.e., main bearing, crankshaft sleeve and eccentric of cam mechanism) form a cover over this oilway and form a reservoir from which the cam sleeve is lubricated via a groove and holes in crankshaft sleeve. From the recess between the two halves of the cam sleeve bushes the oil is distributed over the

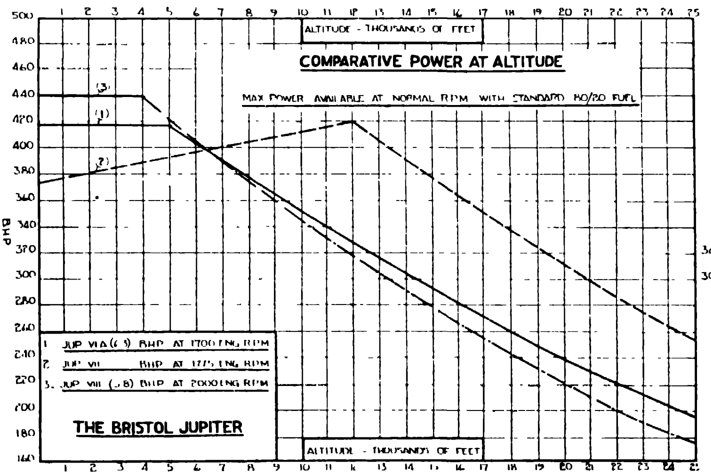


Fig. 659.—Chart Showing Comparative Power of Various Series Bristol Jupiter Engines at Altitudes.

surface of the bushes by spiral grooves. The intermediate bearing, i.e., the roller bearing immediately in front of the front web, is splash lubricated by oil thrown off from there. The eccentric of the cam gear has two recesses formed on its bore, from which holes communicate with the compound pinion Oil from the pinion and from the cam sleeve lubricates the rest of the cam mechanism and the front main bearing. A spring-loaded brass ring on the crankshaft makes contact with the surface of the thrust bearing housing, and prevents the oil from leaking out through the front.

Of the drives, etc., on the back of the engine, the white-metal bearing o the magneto drive sleeve is supplied with oil bypassed direct from the pump chamber, and led by a duct drilled in each magneto drive spindle to its bearing. A duct in the rear cover leads to the plain bearing of the C.C. driv

spindle, and from there upwards to the spindle of the gas starter distributor. In the later types of "Jupiter" there is an external oil pipe which supplies the upper part of the gas starter distributor.

As regards the scavenger system, surplus oil drains from the front main crankshaft bearing through holes in the fixed internal gear plate into the front cover, and from there through a passage communicating with the front "leg" of the external sump under the engine. The oil from the interior of the crankcase drains, through holes in the bottom, into the rear "leg" of the sump. At the lowest point of the rear wall of the crankcase there is a hole through which drains the oil from the various assemblies on the rear cover.

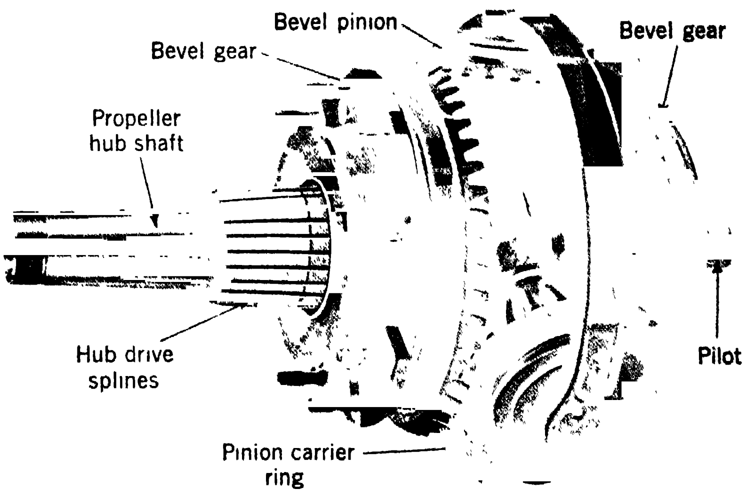


Fig. 660.—The Jupiter Reduction Gear Uses Bevel Pinions and Gears and is of the Farman Type. It is a Modification of the Differential Gearing of Automobiles.

The two oil pumps, pressure and scavenger, are of the gear type, and form one unit, housed in a chamber in the rear cover of the engine. This chamber communicates with the rear end of the hollow crankshaft. Formed integrally with the rear cover are two horizontal cylindrical filter chambers placed one on each side of the pump unit, that on the right housing the scavenger filter, and that on the left the pressure filter. The outer ends of the filter chambers are closed by hollow screwed plugs, and to these are attached the filters themselves.

The pump unit is built up in sections clamped together between end plates by four long bolts, and the rear end plate carries a pressure relief valve. The aluminum gears which form the pumps comprise driving pinions and idler pinions, and are mounted on hollow parallel spindles. The upper is the drive spindle, and has formed on it two grooves engaging with dogs formed in the driving gears of both pumps. The difference in capacity between pressure pump and scavenger pump is obtained by making the pinion of the latter longer than the former. The idler spindle (the lower) is of larger diameter than the

driver spindle, and serves to convey the oil from the pressure pump to the crankshaft. The sectional views at Fig. 658 B should explain the arrangement.

The Salmson AB9 Engine.—The air-cooled AB9 engine was registered on the fifth of August, 1924, at a nominal power of 230 horsepower for 1,700 r.p.m. It was fitted to the four engine Bleriot machine piloted by Bizot

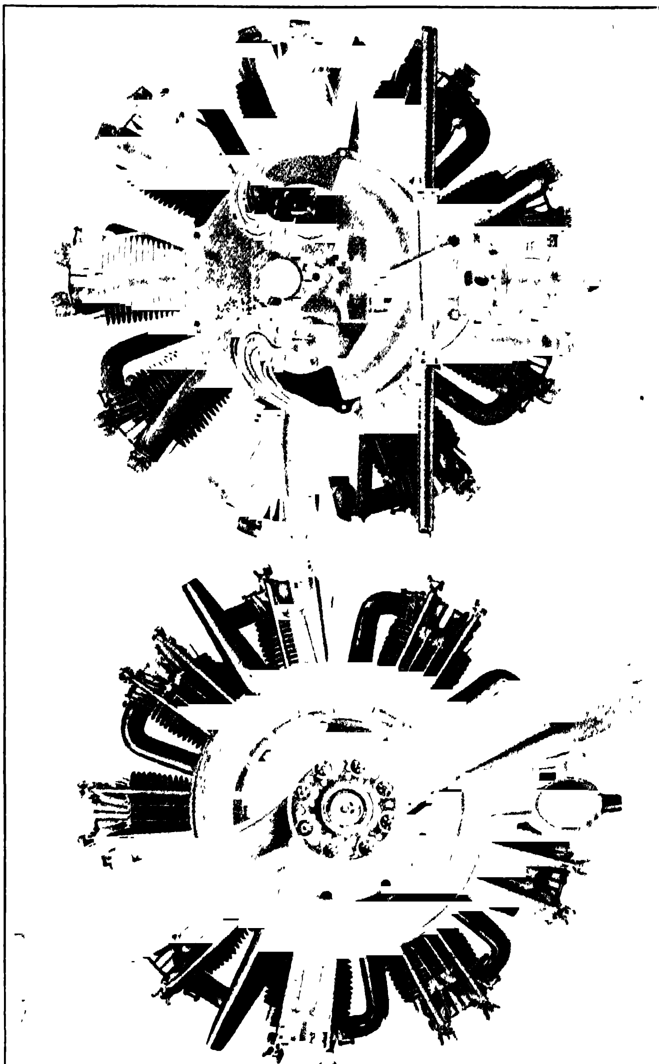


Fig. 661.—Front and R View Salmson AB9 230 Horsepower Av Engin No E Ring Mounted on Front of Motor.

and Villechanoux at the "Grand Prix des avions de Transport" 20th-24th August, 1924. In spite of unfavorable atmospheric conditions and though it was the first time this engine was fitted to a machine, it accomplished the three return flights between Paris and Bordeaux, i.e., 3,090 kilometers

in three consecutive days without the occurrence of the slightest trouble. The average speed for the last Bordeaux-Paris flight was over 200 kilometers per hour.

The AB9—230 horsepower engine, as shown at Fig. 661, is now actually fitted to the following machines: Latham hydroplane with catapult start. Twin engine Farman machine, commercial type Goliath, Training Morane-Saulnier machine 120 ET 2 type. Training Caudron machine, C 59 type.

Used on the Caudron machine the AB9 engine of 230 horsepower put up the following performances hitherto unattained:

Air-cooled Salmson engine AB9 type—230 Hp	Other make water-cooled engine of equal weight
1,000 m in 2 min 20 sec.	1,000 m in 4 min. 30 sec.
2,000 m in 5 min 17 sec.	2,000 m in 14 min 00 sec.
3,000 m in 9 min 02 sec.	3,000 m in 17 min. 24 sec.
4,000 m in 13 min 48 sec.	4,000 m in 29 min. 03 sec.
5,000 m in 23 min. 11 sec.	4,320 m in 35 min 29 sec.
5,420 m. in 33 min 08 sec.	

It will be seen that the ceiling for this machine which was limited to 4,320 meters with an engine of another make, attained 5,420 meters with the Salmson AB9—230 horsepower engine.

Characteristics.—The AB9—230 horsepower engine is of the stationary radial, air-cooled and four-stroke type, having nine cylinders. Bore: 125 millimeters, stroke 170 millimeters, cubic capacity 18,765 cubic centimeters, compression ratio 5 to 5.4. The motor is suspended by the rear crankcase. Nominal power at 1,700 r.p.m., 230 horsepower, cylinders in the wind. Fuel and oil consumption at 1,700 r.p.m. developing 230 horsepower:

	Aviation Petrol	Castor Oil
Per hour	56 kgs. 35	4 kgs. 6
Per horsepower hour	245 gr.	20 gr.

The engine dimensions are: length one meter, diameter one meter eighteen millimeters. Engine in complete running order with propeller hub, carburetor and magnetos, without silencer, weighs 265 kilograms. The AB9 engine is adapted for use as a tractor or pusher, the propeller being mounted direct on the crankshaft which is fitted with double thrust bearings for this purpose. The engine revolves in a clockwise direction for an observer standing in front of the engine and looking at the propeller. Although easily started with the propeller by means of a starter magneto, the engine is provided with a distributor fitted at the front allowing a start from compression.

The nine steel cylinders are fitted with aluminum-finned jackets and are fixed separately on the crankcase by studs and therefore can be removed independently of each other. The master connecting rod, which is balanced and made of special steel, revolves on a white metal lined central bearing of large dimensions. The crankshaft of nickel-chrome steel carries two counterweights so arranged as to balance the whole group of connecting rods in all their positions and at all speeds. The distribution operated by a circular cam acts on the valves through roller tappets, rockers and adjustable rods. A single inlet pipe located in rear crankcase feeds each cyl-

inder and receives the gases from a manifold connected to the carburetor which is fitted with an automatic altimetric correcter. Ignition is by two Salmson magnetos GG 9, type 25, and two plugs per cylinder. Lubrication is effected by pump returning to tank the oil collected from crankcase. A circular manifold forming an exhaust silencer and fitted with clearing pipes is supplied on special order. The arrangement of this silencer and manifold is clearly shown in the propeller end view of the engine.

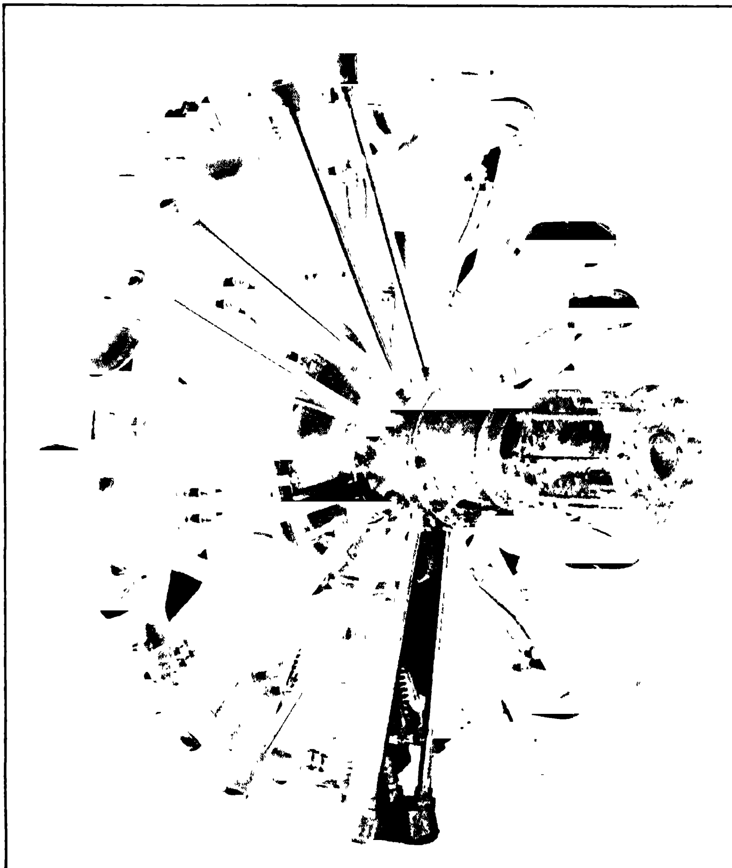


Fig. 662.—Three-Quarter View of Menasco-Salmson Nine-Cylinder Air-Cooled Radial Engine.

Menasco-Salmson Engine Model B2.—The Menasco Motors Company, Los Angeles, California, are converting original French Z9 water-cooled Salmson engines to what they term the model B2 Menasco-Salmson nine-cylinder radial air-cooled engine developing 260 horsepower. The converted engine is shown at Fig. 662 and the sectional view at Fig. 663 clearly

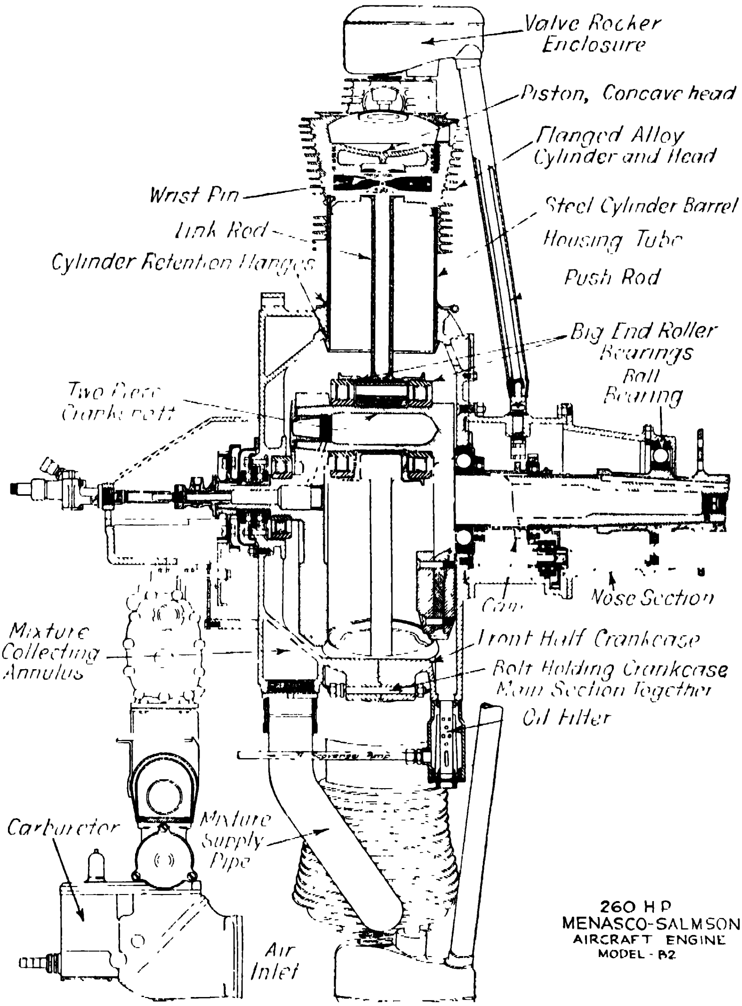


Fig. 663.—Sectional View of Menasco-Salmson Aircraft Engine, Model B2, Showing Construction of Parts.

shows the internal construction. A group of the important parts are shown at Fig. 664. The principal changes from the original French engine include cylinders, pistons, all bearings, valves, magneto mounting, intake manifold, oil pump and oil circulating system. In fact, about 66 per cent of the converted engine is of domestic manufacture.

The cylinder construction used is that in which a cast alloy head with integrally flanged jacket member is assembled on a steel sleeve or barrel which does not have any flanges machined thereon. The crankcase is

divided on the engine center line which makes it possible to hold the cylinders in place by clamping them in suitable bosses on the housing, the lower end of the cylinder barrel being provided with flanges machined thereon to locate the cylinder. The big end bearings of the master connecting rod are of the ball bearing type as used on the Gnome engine and also found on recent models of the Ryan-Siemens and other motors. The crankcase half

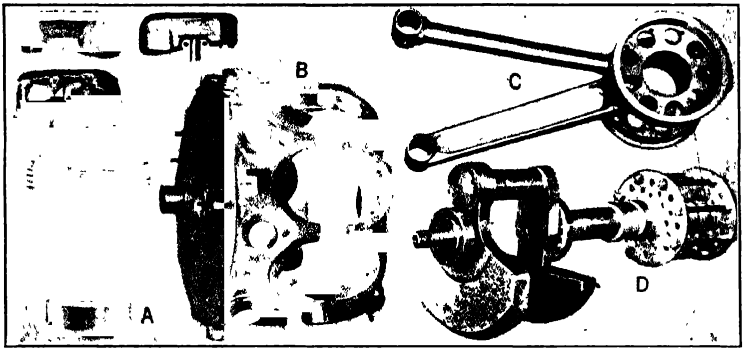


Fig. 664.—Group of Important Parts of Menasco-Salmson Aircraft Engine. A—Cylinder, Showing Valve Mechanism Enclosure. B—Divided Alloy Crankcase. C—Master Rod and One of the Link Rods. D—Crankshaft and Propeller Hub.

or section at the front carries a nose piece and a cylindrical member housing in the valve lifting cams and carrying the cam followers. The crankshaft is made in two pieces, the tapered end of the crankpin being tightly forced into a female taper machined in the anti-propeller end crank web by a clamping member that screws into the crankpin. This construction makes it possible to install the big end ball bearings without difficulty. The crankshaft assembly revolves on two large ball bearings and one roller bearing The front part or propeller end of the crankshaft carries counterweight members that are bolted on but the rear counterweight is forged integrally. The valve gear is all enclosed and the engine is remarkably clean in exterior arrangement. The main dimensions are given in the assembly drawing at Fig. 665.

SPECIFICATIONS

Nine cylinder fixed radial type.
Power range, 230-290 Hp. at 1150 t 1750 R.P M.
Cruising speed approximately 1350-1400 R. P.M. at which speed the power output i is 250 Hp. and the fuel consumption is 12 gallons of gasoline and one quart of oil per hour.
Weight, 540 lbs. dry, including propeller hub.
Overall diameter 49⅛ inches.
All working parts enclosed.
One piece master connecting rod and built up crankshaft
Grouping of all accessories at rear of engine
Dual magneto ignition supplied by two magnetos from rear of engine.
Dual Zenith carburetor.
Scavenger pump incorporated, insuring dry crankcase and freedom from fouling troubles, even at the slowest idling speed

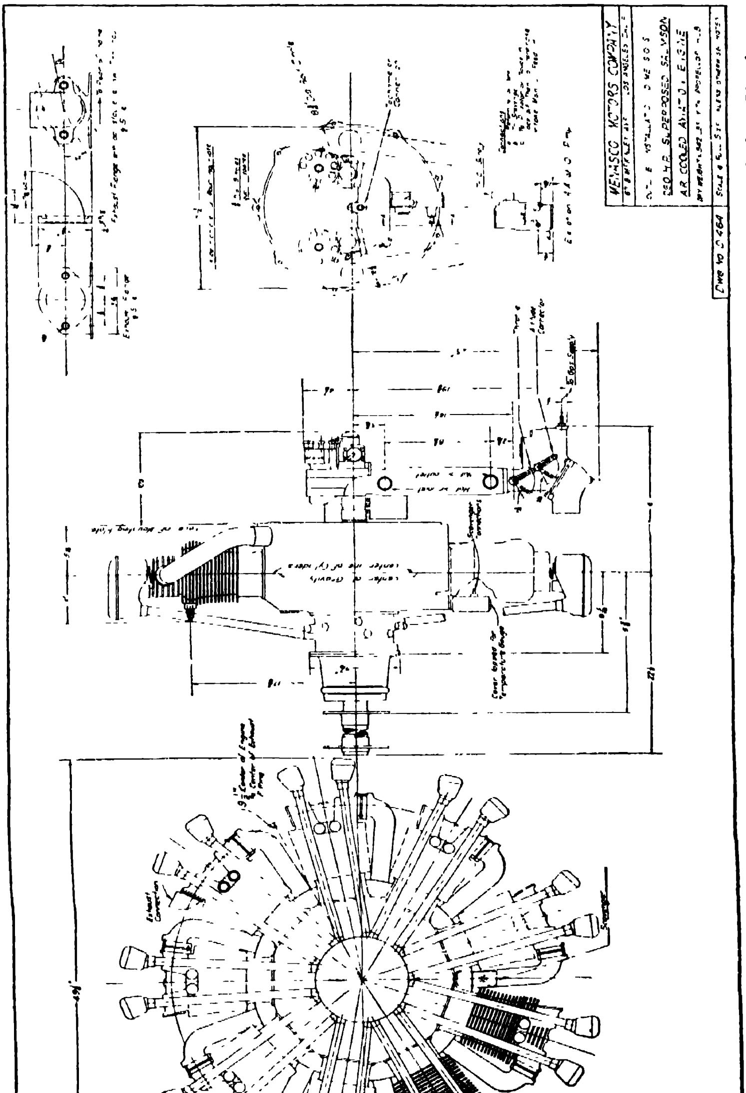


Fig. 665.—Outline Drawing Showing Installation Dimensions of 260 Horsepower Menasco-Salmson Aviation Engine.

Curtiss Chieftain Engine.—Flight tests were recently completed at Mitchel Field, N. Y., on the new 600 horsepower Curtiss "Chieftain" one of the largest air-cooled aircraft engines in this country. The tests were conducted with the engine installed in a two-seater Curtiss Falcon, standard observation and attack plane of the Army Air Corps. The plane was flown by Lieut. E. P. Gaines, Army Pilot stationed at the Curtiss factory, and by "Casey" Jones, veteran Curtiss pilot. Equipped with the "Chieftain" engine, the "Falcon" showed a performance that was superior to that of any other two-seater in the service. Its top speed was 158 miles per hour, and the service ceiling 22,350 feet, while the initial rate of climb was 1,870 feet

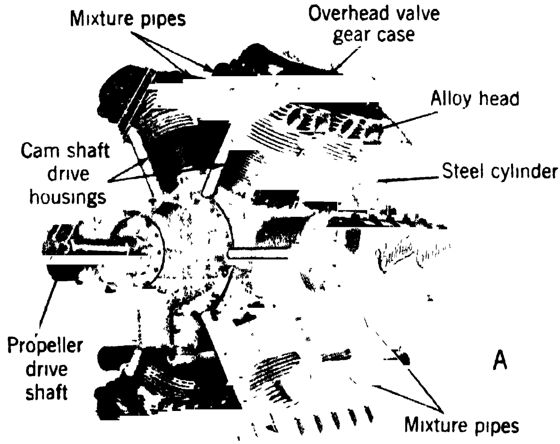


Fig. 666 A.—View of the Curtiss "Chieftain," a Twelve-Cylinder Aviation Engine of the Hexagon Type. A Shows Propeller Drive End Viewed at an Angle.

per minute. The most remarkable feature of this performance is the speed of 158 miles per hour, which is exactly the same as could be obtained from a water-cooled engine of the same power in the same plane. Curtiss engineers point out that this is the first time in history that air-cooled engines have been able to compete directly with water-cooled types in pure speed Usually, the substitution of an air-cooled engine for a water-cooled engine of the same power, while producing improved climb and ceiling, has resulted in a sacrifice of several miles per hour in top speed. The excellent speed characteristics of the Chieftain engine is due to its unusual design, which is different from that of any other air-cooled engine. Instead of having one row of cylinders arranged radially, as is the common practice the Chieftain has two rows one behind the other, with six cylinders, arranged hexagonally, in each radial group. This arrangement materially reduces the overall diameter of the engine, thus reducing the head resistance and increasing the high speed and is shown at Fig. 666 C which is

a direct side view. The frontal area per horsepower of the Chieftain engine is approximately one half of the conventional nine-cylinder air-cooled engine. The Chieftain engine has been under development by the Curtiss company for over two years, with the assistance and guidance of the Air Services. It performed excellently throughout the trials.

According to Arthur Nutt, Chief Engineer of the Curtiss Aeroplane and Motor Co., Inc., it was in April, 1926, that a systematic study was first started on the design of a 600 horsepower air-cooled aircraft engine. The first steps in this study were to analyze the types of engines in use at that time and then to study the possibilities of the different forms of engines which would be suitable in the large size contemplated. The types that

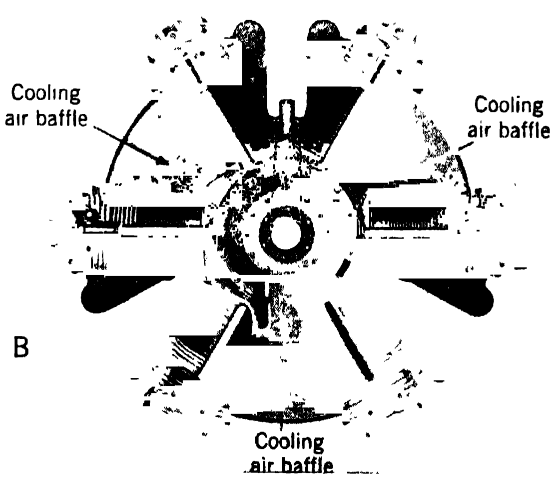


Fig. 666B.—Direct Front View of Curtiss "Chieftain" Twelve Cylinder Aviation Engine.

were finally selected for study were as follows: Nine Cylinder Single Row Radial, Fourteen Cylinder Two Row Radial, Sixteen Cylinder X, Twelve Cylinder Vee, Twelve Cylinder Hexagon. In making this study ten important characteristics were borne in mind. 1. Low weight per horsepower. 2 Head resistance and propeller efficiency. 3. Visibility from the pilot's cockpit. 4. High crankshaft speed. 5. Overhead valve gear for high speed. 6. Exhaust arrangement. 7. Control of cooling air. 8. Application of reduction gears. 9. Overall dimensions particularly diameter and length. 10. Smoothness of operation.

Nine Cylinder Single Row Radial.—This type would require an engine of from 1,800 to 1,900 cubic inches to develop about 600 brake-horsepower at a speed in the neighborhood of 1,900 r.p.m., which is probably a rather optimistic speed at which to expect to run an engine of this power and displacement, owing to the fact that the size of the cylinder bore is reaching a point where cooling is difficult, and the reciprocating weights on one crankpin (even

though it may be of the split crankshaft and solid big end type) would be a difficult problem. The outside diameter of a nine cylinder radial engine of this power would be 56 inches to 60 inches in diameter which presents a very large frontal area with severe blanketing of the propeller, resulting in poor propeller efficiency. The added diameter increases the resistance so

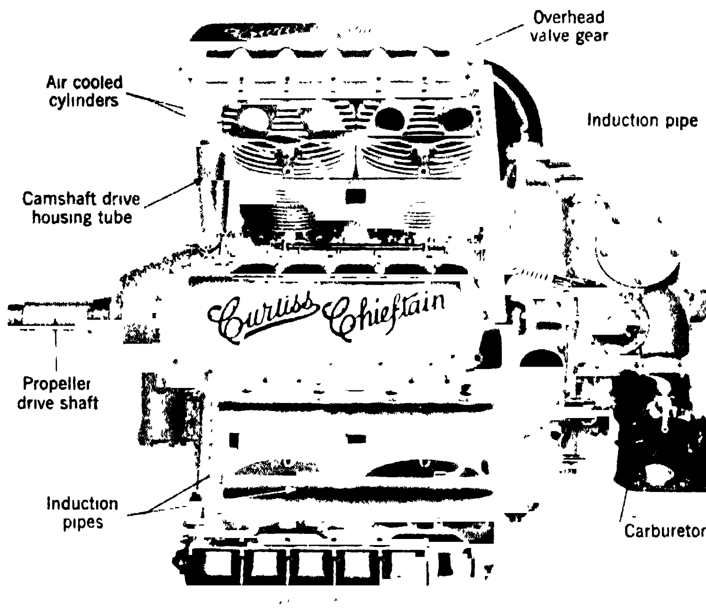


Fig. 666C.—Direct Side View of the Curtiss R-1600 "Chieftain" Engine, a 600 Horsepower Twelve-Cylinder Air-Cooled Hexagon Type.

much that it has been found by experience that the larger radial engines in pursuit planes make practically no more speed than the lower horsepower radial engines with the smaller diameters. Of course, the rate of climb is increased but this does not offset the disadvantage of carrying high powered engines using more fuel without gaining more top speed.

The exhaust problem on a nine cylinder radial becomes more difficult as the size of the engine increases. The manifold must be made very large in order to decrease the back pressure. The manifolding assembly then becomes very heavy, unreliable and cumbersome, resulting in the necessity of locating it between the propeller and cylinders where it undoubtedly has a detrimental effect on the cylinder cooling as well as making the cylinders very inaccessible. A large diameter radial engine does not lend itself to good cowling and the adaptation of shutters for control of cylinder temperatures and oil temperatures under various weather conditions. It is necessary to use push rod valve mechanism with the attendant difficulty of

lubrication of the rocker arms, and the ball and socket joints. The lubrication cannot be fully automatic without adding a great many pipe fittings and tubing which would not be reliable, would increase the expense and would be very unsatisfactory.

Fourteen-Cylinder Two Row Radial.—This type of engine has been used by several manufacturers in powers up to 450 horsepower, and is objectionable on account of the lack of satisfactory cooling of the rear row of cylinders, since the cylinder spacing is so close when the outside diameter of the engine is held to a minimum that the rear cylinders get hot air from the front cylinders. The push rod valve mechanism is also unsatisfactory on account of the necessity of staggering the cylinders to a great degree in order to keep the engine diameter down, resulting in high angularity on the push rods and possibilities of increased wear on these parts. The weight per horsepower on the double row radial is slightly higher than the single row radial but it has the advantage of a small diameter which was the reason for investigating this type of engine. The displacement would have to be approximately 1,800 cubic inches, which would allow smaller cylinders than could be obtained in a nine cylinder type. Both these engines, the nine cylinder radial and fourteen cylinder using push rod valve gears, are probably limited in engine speed, although this engine speed has in the past few years been increased slightly over what was originally thought could be used with this type of valve gear. There is no question, however, that the push rod valve gear is inferior to the overhead type when high engine speeds are used.

Sixteen-Cylinder X.—The X sixteen-cylinder engine has not been given a great deal of consideration on account of the large number of cylinders making the engine more expensive and the necessity of using very heavy counterbalances on the crankshaft to make the engine run smooth. The engine would also be heavier than the radial types on account of the longer crankshaft, although the diameter would be very satisfactory.

Twelve-Cylinder Vee.—This type of engine has been built successfully with air cooling, it has one very great objection, namely, its overall length which automatically gives a high weight per horsepower as compared with the other types of air-cooled engines. This overall length is necessary on account of the large cylinder centers necessary to get cooling on each cylinder barrel and on the cylinder head. The air-cooled Vee engine is eight or ten inches longer than a water-cooled engine of the same bore, however, the engine has a very great advantage of being able to run at high engine speeds on account of the overhead valve gear and the light reciprocating parts on the crankshaft. The exhaust arrangement is very satisfactory, particularly when the engine is built in the inverted form. The cooling air to the cylinders can be controlled by means of shutters, if necessary, and the air to the crankcase can also be controlled by shutters. One of the biggest problems with this engine, however, is proper intake manifolding.

Considering all of these types of engines the rotary inductor and supercharger have been included in the study of the design, therefore, when connecting the supercharger in the Vee engine to the cylinders, the straight or gallery type manifolds have usually been employed which are extremely unsatisfactory at high altitude, owing to the fact that the gas distribution

with this type of manifold is very poor. The engine runs very well at sea level where the manifolds are not subjected to the cold air blast and where the heat of the mixture is higher owing to the higher initial temperature of the charge. In order to apply a satisfactory manifold to this engine weight and frontal area are increased, inasmuch as the manifold arrangement must be on the outside of the cylinder banks.

Twelve-Cylinder Hexagon Type.—After making the above study it was decided to attempt a combination of the radial and Vee engine which would satisfactorily combine the good features and do away with the objectionable features of both. The type of engine selected is that for which the Curtiss company has coined the name "Hexagon." In other words, the Vee engine was cut into three sections, these sections of four cylinder Vee engines being placed in radial form 120 degrees apart, resulting in a two row radial twelve-cylinder engine, one row directly behind the other. By blanking off the rear end of the exhaust Vee in each of the three Vees, Vee engine cooling was obtained.

The feature of the low weight per horsepower of the radial was partially maintained, as there is no question that the single row radial is the lightest form of engine at a given r.p.m. and displacement that is known today. However, by increasing the engine crankshaft speed this difference was offset. Second, the head resistance was kept very low, the engine outside diameter being 45 inches, and the cowling diameter 39 inches, which results in high propeller efficiency as the ratio of the diameter of the propeller to the diameter of the engine becomes larger than on the big radial engines, leaving the propeller tips in clear unobstructed air in a symmetrical form around the engine. In fact, the propeller has less flutter when operating in front of a symmetrical body than it would behind a form of engine such as the inverted Vee, particularly if the propeller runs very close to the engine. On account of the small diameter and a short engine very high visibility was obtained. With six cylinders in a radial row there are large spaces, 60 degrees between each cylinder bank, which permits visibility as obtained on a 39-inch diameter since the 45-inch diameter prevails only at the overhead valve gear covers which extend for only a very short part of the circumference and are streamlined easily.

With only six cylinders on a crankpin the weight of reciprocating parts was greatly reduced permitting higher crankshaft speeds. Overhead valve gear similar in design to the D12 valve gear was used which again permitted the higher crankshaft speeds. The exhaust arrangement is exactly the same as on any Vee engine with the addition of an extra row of exhaust ports at the bottom of the engine which can be manifolded with a muffler in a single row at the two sides and bottom adding practically no head resistance and not interfering with visibility. The cooling air to the cylinders can be controlled as on the Vee engine. Reduction gears of either the concentric type or the spur type can be used, the latter possibility being a very great advantage on the engine and one which cannot be used on any other form of engine without interfering with cylinder cooling or increasing the frontal area of the engine, as would be the case on the inverted Vee engine should the reduction gear or the spur type be raised above the crankshaft center line. The application of the spur gears in this way on the in-

verted Vee engine would also entirely ruin the visibility from the pilot's cockpit. The spur reduction gears would not interfere with cowling or visibility on the Hexagon engine and they would raise the center of the propeller shaft, giving more clearance for the propeller which naturally would be larger in diameter if run at a slower speed. The overall length of the Hexagon type of engine is only about eight inches more than the single row type which is a negligible figure when the installation in an airplane is considered. There is also no question that the larger the number of cylinders on an engine of this power the smoother the operation of the engine will be. Twelve cylinder torque has been demonstrated repeatedly to be very much more satisfactory than the torque from a smaller number of cylinders of the same size when the engine is run at the same crankshaft speed.

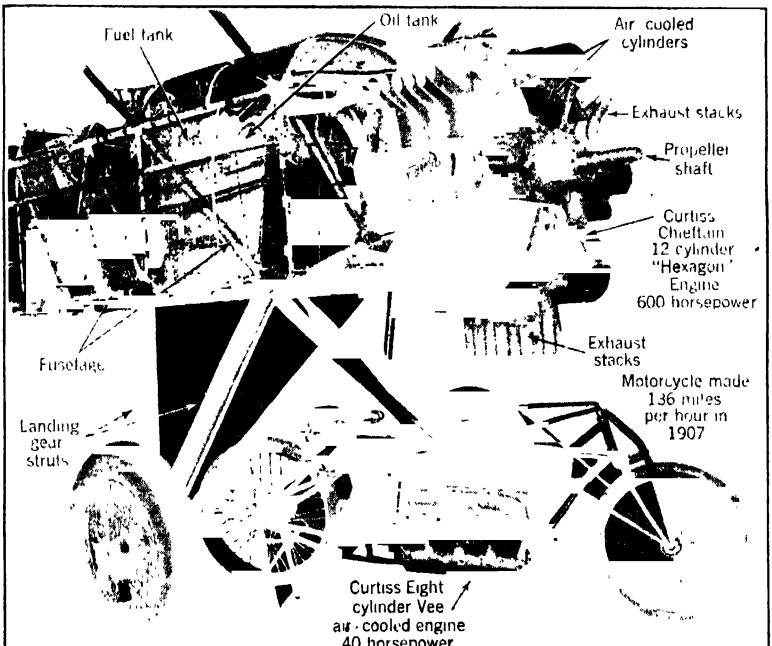


Fig. 666D.—An Interesting Contrast in Design. The First Air-Cooled Curtiss Vee Aviation Engine was Tested on a Motorcycle. Compare This with the "Chieftain" Engine Shown Above It.

It is not possible to completely balance the nine-cylinder radial engine or any other single row engine using the articulated type of rods. These engines do not run as smooth as the twelve cylinder, but they have been found to be satisfactory in service. The balance of the articulated rods on the Hexagon type is perfect, inasmuch as one row of the cylinders completely balances out the other row of cylinders on the opposite crank throw and it was only necessary to put enough balance weights on the crankshaft to take care of the unbalanced couple existing.

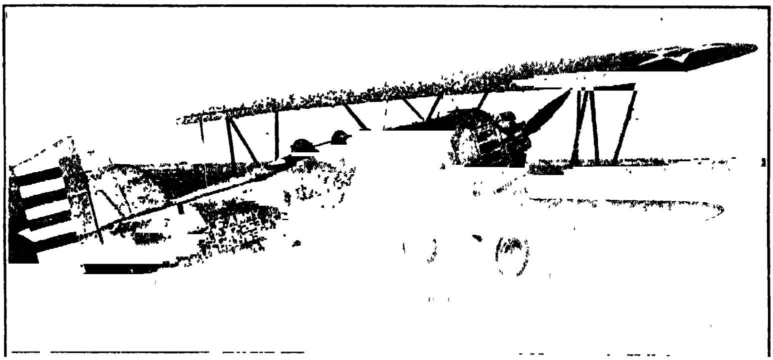
The above outline describes roughly the arrangement of the engine, however, a few details making this combination possible are given below. The cylinder construction is of the conventional type with the exception that a four valve flat head cylinder is used similar to the water-cooled Conqueror engine. Bronze seats are inserted in the aluminum cylinder head and the steel cylinder is screwed in the aluminum head in the usual manner. Each cylinder in a bank has a large pilot on the top end which fits into a casting bridging the two cylinders. This casting is held in place with studs and nuts and carries the double camshaft bearings. The two camshafts on each bank of two cylinders are driven by spur gears at the propeller end, one of these spur gears being mounted on an idler shaft below the two camshafts. The idler shaft is driven through bevels and a master gear on the front end of the crankshaft, all of the vertical shafts being driven from this master gear. Each pair of camshafts has a serrated face coupling for timing adjustment.

The crankshaft, which is a two throw, 180 degree crank, is mounted on two Norma-Hoffman roller bearings one at each end. The center main steel backed babbitt lined bearing is mounted on a large split circular bearing support which is large enough to clear both crankpins enabling the shaft to be dropped into the crankcase which is of the barrel type. The crankcase is split at right angles to the crankshaft between the two rows of six cylinders being bolted together on inverted flanges on the inside of the crankcase before the cylinders are put in place. This gives a very clean exterior on the crankcase and the internal flange forms a support for the center main bearings. The nose piece on this engine which is clearly shown at Figs. 665 and 666 contains only the cluster of bevel gears for driving the camshaft, and the oil pressure strainer. The strainer is located at this end of the engine for the purpose of accessibility and permits the use of an oil seal for forcing oil into the crankshaft for lubrication purposes. A large deep groove ball bearing for both radial and thrust purposes is used at the forward end of the nose of the engine on the crankshaft.

The connecting rods are of the split type, very carefully keyed together with integral keys. Owing to the fact that the number of cylinders are even, the rods are perfectly symmetrical permitting the bolts to be placed very close to the babbitt lined bearing shells, thus eliminating the big objection which is always present in a radial engine with an odd number of cylinders in a row. The connecting rod in the single row radial engine must be unsymmetrical making it very hard to get a satisfactory bolting arrangement on the split connecting rod. Pistons are of the hollow head type and are of the conventional ribbed design which have been used by Curtiss for many years.

The engine is fitted with a rotary inductor or supercharger which will give sea level power at 12,000 feet. It is of the General Electric Company's centrifugal type and is mounted in the rear of the engine as shown at Fig 666 C, being driven by four spur gears, two being on a jackshaft. One main shaft is carried through the diffuser of the supercharger to drive all accessories which are mounted on the back of the engine. A very unusual and novel method of mounting accessories has been employed on this engine. All accessories are mounted in such a position that they are accessible when an engine is installed in an airplane.

The starter and magneto are mounted on opposite ends of a horizontal cross shaft driven from very large bevel gears from the shaft which was carried through the diffuser. This same shaft through the diffuser carries a larger helical gear which drives two vertical shafts in the rear gearcase. Two distributors are driven from helical gears from each of these two shafts, the oil pump being driven off the lower end of one of these shafts and the gasoline pump off the lower end of the other shaft. The generator is mounted in a vertical position, on the top of the gearcase driving through bevel gears. In other words, there are only three bevel gears on the rear end of the engine, driving accessories. In addition the oil pump is driven



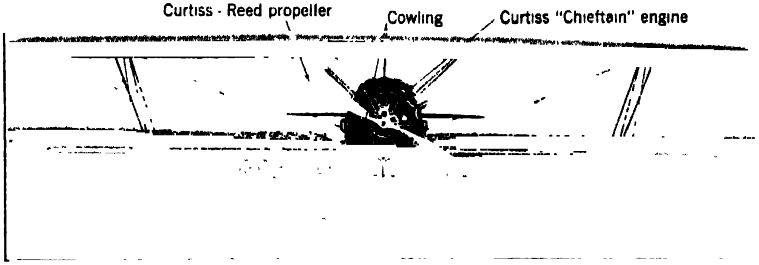


Fig. 667 A and B.—Views Showing Installation of Curtiss "Chieftain" Engine in U. S. Army Airplane. Note Effective Cowling Possible and Smooth Entry of Nose of Plane Fitted with Hexagon Type Engine.

from the lower end of one of these shafts and the fuel pump from the lower end of the other. The generator is mounted in a vertical position on top of the gearcase, and is driven through bevel gears. There are thus three bevel gears at the rear end of the engine for driving accessories. The two gun control drives are taken from the top ends of the vertical shafts, while the tachometer drives are taken from the rear ends of the camshafts, as desired.

A carburetor intake elbow is cast integral with the rear gearcase and a single Stromberg carburetor with economizer is fitted. Lubrication is by the regular Curtiss system, to which have been added a number of special features that will be described. Oil from the pressure pump is led through a steel tube to the pressure oil strainer on the nose of the engine; it passes

through this strainer into the crankshaft and thence to the two connecting rod bearings and the center main bearing, which is a plain bearing. To the bearings of all the articulated rods the oil is index-fed, and the spray from these bearings lubricates the cylinder walls and the piston pin bearings Oil under pressure is index-fed to all of the plain bearings in the gearcase of the engine and also to the ball and roller bearings wherever this was found necessary Oil is conducted to the camshaft bearings through the vertical drive shafts and is returned to the main crankcase by geartype oil pumps formed by casings built around the spur gears which drive the camshafts. Making these gears do the additional duty of oil pumps called for very little weight increase. Two main scavenging oil pumps are provided, one taking oil from the front and the other from the rear end of the engine, both returning the oil to an outside tank.

One of the most interesting features of the engine is the manner in which the cooling problem has been solved. In the past it has been considered a very difficult task to assure equal cooling of air-cooled cylinders where one or more of a bank are masked by the forward cylinder thereof In the Chieftain every other space between cylinder banks is baffled at the rear by a plate to which the cowl is fitted snugly. The air current induced by the motion of the plane, upon striking this baffle, is deflected sideways against the rear cylinders and compelled to pass through the space between the two cylinders of a bank and around the back side of the rear cylinder, from the exhaust compartment to the inlet compartment. From the inlet compartment it passes into a space in the fuselage back of the engine, whence it escapes through louvres in the cowling at the forward part of the Curtiss Falcon plane.

Another interesting problem connected with the design of this engine was that of the firing order. A single row radial engine requires an unequal number of cylinders if explosions are to be equally spaced. In analyzing the problem as relating to the hexagon type, it was found possible to jump from the front to the back row and to the front again. Explosions evidently must be spaced 60 degrees of crank motion, which is the angular distance between cylinder banks. Thus, after one forward cylinder has been fired, the cylinder next forward in the direction of rotation (clockwise) may be fired, or, alternately, the rear cylinder of the bank directly opposite this one. Thus there are at least three possible firing orders. Of these the one in which front and rear cylinders always succeed one another was chosen.

The tests conducted on this engine during the past eight months have indicated that the engine is a very satisfactory type. It develops 615 brake-horsepower at 2,200 r.p.m. The weight, including exhaust flanges, exhaust heater, including the heater on the induction passage elbow and the throttle barrels of the carburetor (this weight is not usually included in the weight of air-cooled engines as built today) is 900 pounds, which gives a specific weight of 1.46 pounds per horsepower which compares very favorably with any air-cooled engine built today. The frontal area per horsepower of this type of engine is approximately one-half of the nine-cylinder engine of the same horsepower. This engine has the same frontal area with less head

resistance on account of its better aspect ratio than the conventional 200 horsepower radial engine and with this decreased head resistance it has the advantage of over three times the horsepower. The engine has been developed primarily for pursuit and observation types of airplanes but with future development and the adaptation of reduction gears it promises to be a satisfactory engine for slower types of planes.

CHARACTERISTICS—CURTISS CHIEFTAIN R1600 ENGINE

Hp. (rated) at 2200 r p m	600
Model	H-1640
Type of engine	Static Air Cooled Hexagon
No of cylinders	12
Arrangement of cylinders	2 radial rows of 6, front cylinders directly in line with rear cylinders
Dia of engine	45 in
Dia of cowling	39 in
Bore	5⅝ in.
Stroke	5½ in.
Displacement	1640 cu. in.
B Hp	615
Ignition system	Splitdorf Magneto
Carburetor	Stromberg NA-U8J
Fuel consumption cruising at 2000 r p m.	.53 lb. per b hp per hr.
Oil consumption	.020 lb per b hp hr.
Speed of propeller	Crankshaft
Rotation of propeller	Clockwise
Weight of engine	900 lb.

Armstrong Siddeley "Leopard" Engine.—Armstrong Siddeley Motors, Ltd, Coventry, England, whose airplane engines have been widely used and whose Jaguar model, fourteen-cylinder air-cooled radial has been standardized for many years past has produced a larger and modified design of that type which has been described in a recent issue of *Automotive Industries.* Known as the Leopard, it has the same number and arrangement of cylinders as the Jaguar and follows the same general lines throughout, consisting of two "banks" of seven cylinders each mounted radially on the crankcase. The new model, rated at 700-750 horsepower has been designed for use in torpedo, heavy bombing and load-carrying aircraft, and is believed to be the most powerful air-cooled radial engine now in production. With a bore and stroke of 6 by 7½ inches and a compression ratio of five to one, it develops 700 brake-horsepower at 1,500 r.p.m. and 777 brake-horsepower at 1,650 r.p m. Its weight complete for installation with bearer plate, propeller boss, dual ignition, carburetor, air intake and short exhaust pipes is 1,415 pounds.

The principal departure from the Jaguar design is that the induction fan, which distributes the mixture to the various cylinders, is geared to run at a higher speed than the crankshaft in order to obtain a better volumetric efficiency, and that four valves are fitted to each cylinder instead of two, this being rendered necessary by the increased cylinder capacity. The crankcase is a one-piece aluminum casting, the front portion carrying the tappet guides, a spigot supporting the front cover and the front crankshaft

bearing. The central portion, or barrel, which carries the cylinders, is heavily webbed inside and outside, while the rear portion has a spigot to support the induction fan and casing, the fuel pump, carburetor and the rear crankshaft bearing.

The steel cylinder barrels, machined all over, are secured to the crankcase by clamping rings of wedge section. The cylinder head, an aluminum casting, finned to secure the maximum cooling effect, is screwed and shrunk on to the cylinder barrel, where it is secured permanently by a threaded locking ring, the joint being steel-to-aluminum, without gasket of any kind

Fig. 668A.—Propeller End of Armstrong-Siddeley Fourteen Cylinder Radial Air-Cooled Engine.

The two inlet and two exhaust valves per cylinder are operated by rockers, which pivot on two spindles mounted on the cylinder head. The spindles at their rear ends are anchored to the top of the head; their front ends are supported by a compensating bracket which is anchored to a point near the bottom of the cylinder head. This bracket is of special steel having a very low coefficient of expansion, with the result that the longitudinal expansion of the cylinder has practically no effect on the tappet clearances.

The valve rockers are operated by push rods and tappets from the cam drum, which is located inside the front portion of the crankcase, the tappet clearance adjustment being on the push rods. The valve seats and valve guides are renewable, the former being screwed and shrunk into the heads, while the latter are a press fit. The sparkplugs are accommodated in adapters screwed and pegged into the heads. The cam drum has three inlet cams and three exhaust cams and rotates at one-sixth crankshaft speed Rollers and tappets transmit the cam motion to the push rods. The pistons are machined all over from "Y" alloy forgings. Each carries two compression and one scraper ring, all three rings being above the piston pin. The

air-hardening-steel piston pin floats in the piston and connecting rod bush, and is located axially.

Each bank of seven cylinders and pistons drives the crankshaft by means of one master and six auxiliary connecting rods. The large end of each master connecting rod carries six anchor pins, to which the inner ends of the auxiliary rods are anchored. The master connecting rods are bushed to take the anchor pins, which float in the bushes and are spaced so as to give an equal compression ratio in every cylinder. The master connecting rods bear on the crankpins by means of white-metalled bushes, which are

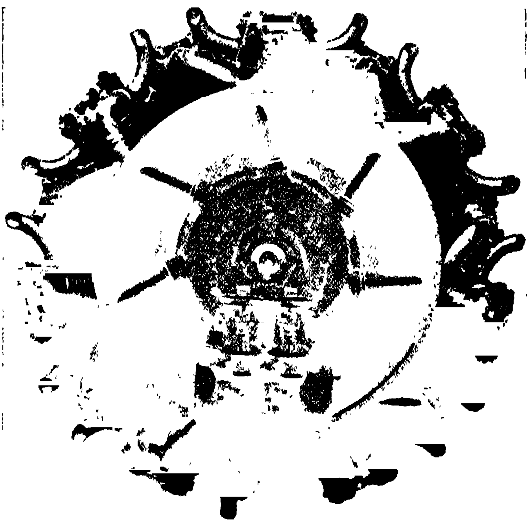


Fig. 668B.—Armstrong-Siddeley Fourteen Cylinder Engine Viewed from Induction End.

made in halves and prevented from turning in the master rods by dowels.

The crankshaft is made in one piece and has two throws set 180 degrees apart, each crankpin carrying one master rod and six auxiliary connecting rods. It is bored for weight reduction, and the holes serve the purpose of distributing the lubricating oil. It is carried by two large roller bearings, one located just behind the rear crank throw and the other just in front of the front crank throw. The crankshaft extends beyond its front roller bearing and this portion carries the timing gear and cam drum, a bevel gear (which drives the oil pumps, magnetos, gas distributor and C.C. gun gear), and the propeller thrust bearing. The rear end carries the spur gear to drive the induction fan. The front and rear webs of the crankshaft carry the necessary balance weights.

Mixture is supplied to the engine by a Claudel Hobson A.V.T. 100 carburetor through the medium of the induction fan which delivers the mixture into an annular induction casing. Thence the mixture passes to the cylinders by means of induction pipes. Experiments have proved that the use of an induction fan of this kind very considerably increases the volumetric

efficiency of the engine and also gives a perfectly even distribution to all cylinders.

The carburetor is supported on an induction elbow attached to the rear end of the engine, as shown at Fig. 668, the controls and air intake pipes being integral with the carburetor and engine. Ignition is effected by two magnetos, each with fourteen terminals; they are accessibly mounted on the front of the engine as depicted in the front view of the engine at Fig. 668 and are bevel-driven from the crankshaft. The oil pumps are mounted on the front of the engine and are also bevel-driven from the crankshaft. The pressure pump, with relief valve, delivers oil through a filter to the center of the crankshaft and thence to the connecting rods and bearings. At the bottom of the crankcase is an oil sump to prevent flooding of the lower cylinders when the engine is stationary. Oil is drawn from this sump by a scavenging pump under the pressure pump, and is delivered to the oil tank on the aircraft. On its way to the tank, the oil passes through the jacketing of the carburetor and induction elbow, thereby positively heating the induction system A gear type fuel pump and relief valve are carried at the rear end of the engine, with a tachometer drive just above; this drive projects toward the rear of the engine to avoid unnecessary bends in the tachometer flexible shaft. Provision for priming is made by fitting a distributing ring at the rear of the engine, the ring having small branch pipes leading to each induction pipe, each branch pipe terminating in a small atomizing jet. Attached to the rear end of the engine is a conical bearer plate, by means of which the engine is mounted in the aircraft.

Service Given by Air-Cooled Engines.—Mr. Roy Fedden, the well known British engine designer of air-cooled engines read a paper on "Air-Cooled Engines in Service" before the Royal Aeronautical Society which gives some very instructive data relative to the life of air-cooled engines in commercial service In a little more than four years, there has been a remarkable change over to air-cooled engines for aircraft. Mr Fedden stated that a large proportion of British Military aircraft employ air-cooled radial engines on various types of machines, and both in England and on the Continent the use of air-cooled radial engines for air transport aircraft of all types is almost universal. In America, the development of the air-cooled radial engine has been synonymous with the general rapid growth of aviation. Without exception, the American long-distance ocean flights of the past two years have all been made with air-cooled radial engines. In attempting to give some information on air-cooled engines in service, there are a large number of motors to choose from, but only those engines which have been in extensive use over a reasonable period of time have been considered.

The largest proportion of aircraft are at present engined with air-cooled motors, and the fact that this type of engine is used so extensively for military and commercial work, and will be used even to a larger extent during the next few years, is sufficient justification for investigating what service these engines are giving at the present time, and what steps can be taken to increase their life and efficiency. To illustrate the difficulty in compiling comparable data, it is interesting to note the difference in man hours shown in the different tables

on the same type of engine. A broad review of the charts would show about equal results from British and American engines. The following figures have been obtained through the kindness of various firms:

TABLE NO. 1

Service Data on Bristol Jupiter VI Engines
Data from Imperial Airways on Middle East Route

Number of machines operated	5
Type of machines operated	3 engined De H Hercules
Number of engines	20
Period covered by data	2 years
Total hours' operation	9,280
Average hours' operation per engine	468
Maximum recorded hours, one engine	960
Average hours between overhaul	400
Average man hours for overhaul—Whites Average man hours for overhaul—Natives	1,356
Average operating, r.p.m.	1,500
Average fuel consumption, gals./hour	19.7
Average oil consumption, gals./hour	0.57

TABLE NO. 2

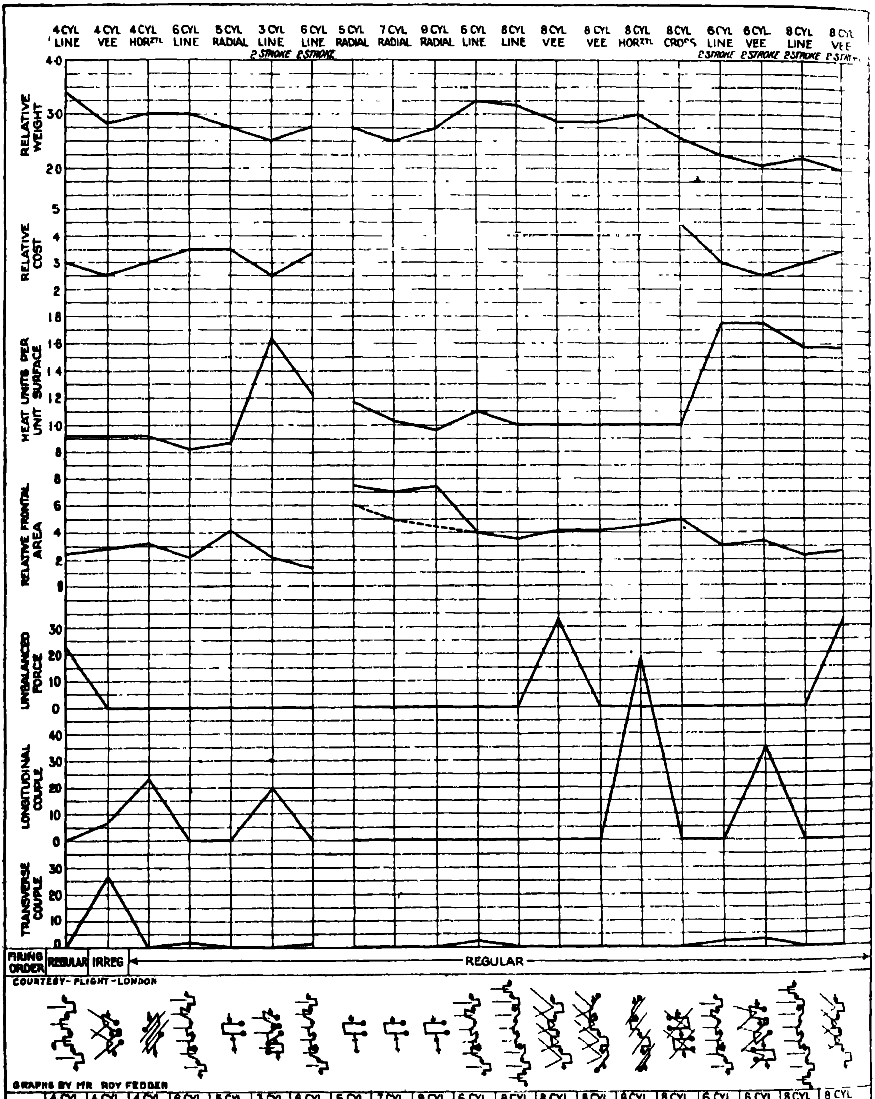
Service Data on Armstrong Siddeley Jaguar IV
Data from Armstrong Siddeley, Ltd., from Imperial Airways Service

Number of machines operated	
Type of machines operated	3 engined A. S. Argosy
Number of engines	
Period covered by data	
Total hours' operation	
Average hours' operation per engine	
Maximum recorded hours, one engine	
Average hours between overhauls	400
Average man-hours for overhaul	480
Average cruising, r.p.m.	1,625
Average fuel consumption	
Average oil consumption	

TABLE NO. 3

Service Data on Gnome et Rhone Jupiter Engines from K.L.M. Royal Dutch Air Line

Number of machines operated	15
Number of engines operated	30
Period covered	3 years
Total hours' operation	25,000
Average hours' operation per engine	830
Maximum recorded hours on one engine	1,860
Maximum running one engine in one year	735 hours
Average hours between overhaul	250
Overhaul staff, skilled	10
Overhaul staff, unskilled	27
Cost per running hour, including maintenance, overhaul and spares	17.5 shillings
Average operating r.p.m.	1,550
Average fuel consumption, gallons, per hour	20
Average oil consumption, gallons, per hour	0.8
Man-hours for complete overhaul	332



TYPE	4 CYL LINE	4 CYL VEE	4 CYL HORZTL	6 CYL LINE	5 CYL RADIAL	3 CYL LINE 2 STROKE	6 CYL LINE 2 STROKE	5 CYL RADIAL	7 CYL RADIAL	9 CYL RADIAL	6 CYL LINE	8 CYL LINE	8 CYL VEE	8 CYL VEE	8 CYL HORZTL	8 CYL CROSS	6 CYL LINE 2 STROKE	6 CYL VEE 2 STROKE	8 CYL LINE 2 STROKE	8 CYL VEE 2 STROKE
BORE × STROKE	4·5 × 5	4 5 × 5	4 5 × 5	4 × 4 5	4 2 × 4 75	4 × 4 5	3 125 × 3 5	5 7 × 6 4	5·1 × 5·75	4 7 × 525	5 375 × 6	4 875 × 5 5	4 875 × 5 5	4·875 × 5 5	4·875 × 5 5	4 875 × 5 5	4 25 × 4 75	4 25 × 4 75	3·875 × 4 375	3 875 × 4 375
STROKE/BORE RATIO	1 125 1							1 125 1												
B.M.E.P.	110 LBS/SQ IN							120 LBS/SQ IN												
B.H.P.	80-100 B H P							200-250 B H P												

An Instructive and Valuable Graphical Comparison by Mr. Roy Fedden of the Characteristics of Various Types of Aviation Engines and How They Compare to Each Other.

TABLE NO. 3A

ervice Data on Gnome et Rhone Jupiter IV Engines Collected from K.L.M. Royal Dutch Air Lines on Eleven Engines of 16,120 Total Running Hours

Component	Average life to date Hours
Crankcase	1,500
Crankshaft	1,000
Valve—inlet	1,000
Valve—exhaust	650
Valve spring	1,500
Valve guides—inlet	615
Valve guides—exhaust	650
Piston	200
Piston ring	165
Scraper ring	270
Cylinder	1,500
Main roller bearings	800
Master rod	750
Articulated rods	1,500
Gudgeon pins	360

TABLE NO. 4

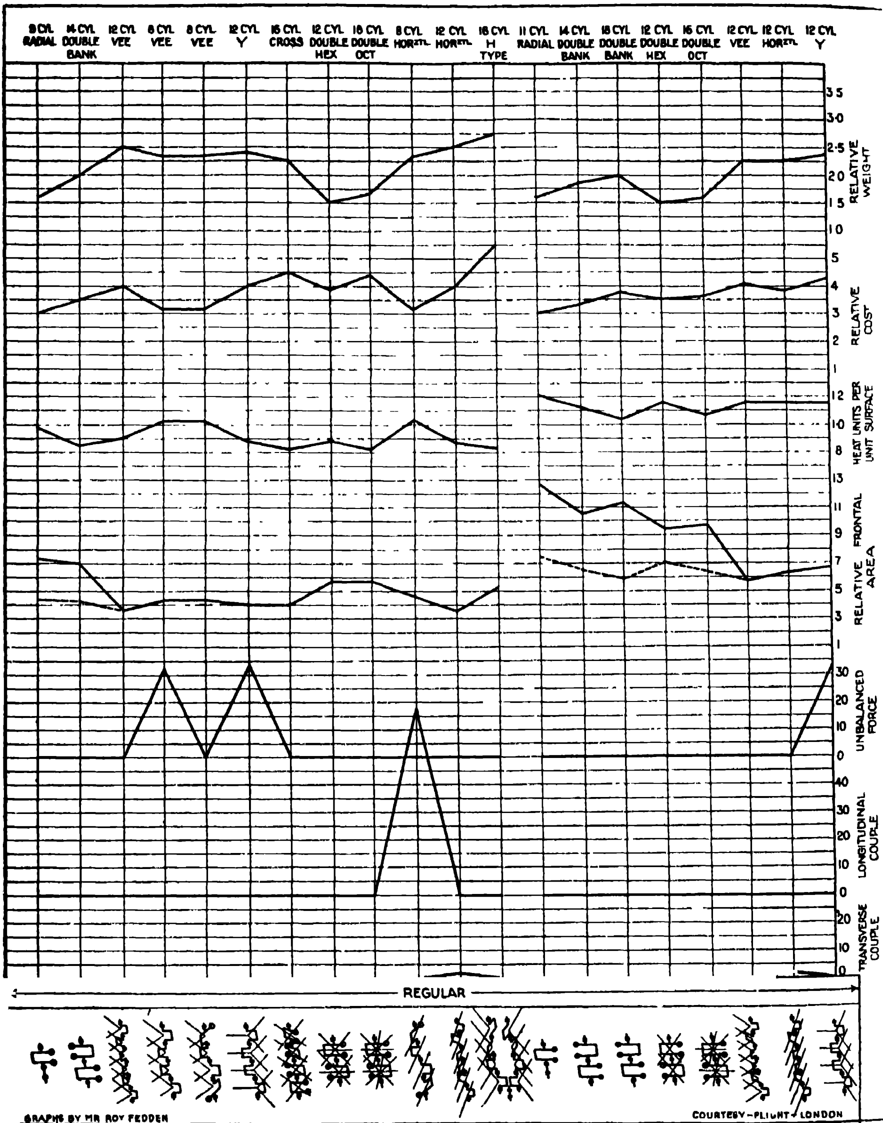
Service Data on Wright Whirlwind Engines from Nine Different Operators

Number of engines considered	91
Total hours' operation	36,464
Average hours' operation per engine	401
Maximum recorded hours on one engine	2,000
Average hours between overhauls	290
Cost of parts per operating hour	4.3 shillings
Average operating r.p.m	1,625
Average fuel consumption, gallons per hour	11.3
Average oil consumption, gallons per hour	0.42

TABLE NO. 5

Service Data on Wright "Whirlwind" Engines from Stout Air Services Incorporated

Motor Number	First Overhaul		Second Overhaul		Third Overhaul		Total	
	Hrs.	Mins.	Hrs.	Mins.	Hrs.	Mins.	Hrs.	Mins.
8108	271	30	130	52	—	—	620	17
7317	259	25	336	24	—	—	696	6
8322	150	57	—	—	—	—	310	35
8168	124	50	—	—	—	—	124	50
8169	124	50	—	—	—	—	124	50
7653	188	13	295	40	175	25	714	57
7324	259	25	271	12	—	—	708	12
7655	308	49	338	43	—	—	768	23
7319	259	25	330	44	—	—	652	44
8945	—	—	—	—	—	—	36	45
8946	—	—	—	—	—	—	36	45
8944	...	—	—	—	—	—	36	45
7800	272	35	—	—	—	—	272	35
7654	167	51	349	42	275	54	793	27
8321	256	26	—	—	—	—	256	26
8521	49	47	—	—	—	—	49	47
							6203	24
verage	207	—	293	—	225	—	388	—



TYPE	9 CYL. RADIAL	14 CYL DOUBLE BANK	12 CYL VEE	8 CYL VEE	8 CYL VEE	12 CYL Y	16 CYL CROSS	12 CYL DOUBLE HEX	16 CYL DOUBLE OCT	8 CYL HORZTL	12 CYL HORZTL	16 CYL H TYPE	11 CYL RADIAL	14 CYL DOUBLE BANK	18 CYL DOUBLE BANK	12 CYL DOUBLE HEX	16 CYL DOUBLE OCT	12 CYL VEE	12 CYL HORZTL	12 CYL Y
BORE × STROKE	4 75 × 5 375	4 1 × 4·625	4 3 × 4 85	4 96 × 5 57	4 95 × 5 57	4 3 × 4 85	3 92 × 4 4	4 3 × 4 85	3 92 × 4 4	4 95 × 5 57	4 3 × 4 85	3·92 × 4·4	5 8 × 6 5	5 375 × 6	4 93 × 5 55	5 625 × 6 375	5 125 × 5 75	5 625 × 6 375	5 625 × 6 375	5 625 × 6 375
STROKE/BORE RATIO	1 125 1												1 125 1							
B.M.E.P.	130 LBS/SQ IN												125 LBS/SQ IN.							
B.H.P.	350-450 B H P												500-600 B H P							

Characteristics of Various Aviation Engine Types Compared Graphically by Mr. Roy Fedden, Well Known British Designer of Air-Cooled Engines to Show Relative Merit

TABLE NO. 6

Service Data on "Jupiter VI" Engines Collected from Twenty Overhauls on Standard Direct-Drive Engines Average Time Between Overhauls 336 Hours

Component	Number off per Engine	Number of Replacements	Average Life Hours	Max observed, Hours to Date	Average Cause of Replacements
Crankcase	1	Nil	1,162	1,413	
Crankshaft	1	Nil	1,162	1,413	
Valve, inlet	18	11	1,091	1,413	Worn on stem or defective seat
Valve, exhaust	18	59	683	1,015	Worn on stem or pitted seat
Valve spring	72	132	839	1,413	Lost pressures
Valve guide inlet	18	8	1,060	1,413	Scored and worn
Valve guide exhaust	18	36	872	1,279	Scored and worn
Piston	9	6	813	1,413	Gudgeon pin bosses oversize
Piston ring	18	164	305	681	Oversize gaps
Scraper ring	9	88	285	904	Oversize gaps
Cylinder	9	2	960	1,413	Scored barrels
Cylinder head	9	Nil	1,162	1,413	
Big end bearing	1	2	872	1,413	White metal collapsed
Artic rod bearing	8	2	1,116	1,413	Wear
Master rod	1	1	996	1,413	Cracked
Artic rod	8	Nil	1,162	1,413	
Gudgeon pin	9	36	697	1,015	Worn in center
Artic rod pin	8	Nil	1,162	1,413	
Prop hub	1	Nil	1,162	1,413	

TABLE NO 7

Service Data on "Cirrus" Engines from the Bristol and Wessex Airplane Club

Number of machines operated	5
Type of machines operated	Moth
Number of engines operated	5
Period covered	2 years
Total hours' operation	1,450
Average hours' operation per engine	290
Maximum recorded hours on one engine	403
Average hours' between top overhaul	120
Average hours' between complete overhaul	360
Man hours for top overhaul	25
Man hours for complete overhaul	100
Cost per running hour, including maintenance, overhaul and spares	1.1*s*.
Average operating r p m	1,800
Average fuel consumption, gals per hour	4
Average oil consumption, pints per hour	0.5

TABLE NO 8

Service Data on "Cirrus" Engines from the A.D.C. Co from Three Aero Clubs

Number of machines operated	4
Type	School Moth and Avians
Number of engines operated	4
Period covered	2½ years
Total hours' running	3,083
Average hours per engine	771
Maximum recorded hours, one engine	826
Average man-hours for overhaul	280

Maximum hours recorded between overhauls	354
Average man hours for overhaul	110
Average hours' life of parts requiring replacement, piston rings, rocker bushes, rear roller races	300
Cylinder barrels	600
Average operating, r p m . ..	1,780
Average fuel consumption, gals per hour	4 5
Average oil consumption, pints per hour	1

QUESTIONS FOR REVIEW

1. What is the cylinder construction of the Lorraine engines?
2. What are the distinctive features of the Cameron Aero Engine?
3. Describe the Curtiss "Challenger" engine.
4. Why does the "Challenger" six cyclinder engine need a two throw cranksha while a seven cylinder needs only one crankpin?
5. What type crankshaft is used in Continental seven cylinder radial engine?
6. What is the Bristol-Jupiter cylinder construction?
7. What are the different compression ratios used with Bristol-Jupiter engine
8. What type of reduction gear is used with Bristol-Jupiter engines?
9. Outline Bristol-Jupiter oiling system
10. What are the distinctive features of the Curtiss Chieftain air-cooled engine

CHAPTER XXXVII

CURTISS WATER-COOLED AVIATION ENGINES

Curtiss Water-Cooled Aviation Engines—Curtiss V-1400 Engine—Curtiss Conqueror Engine—Curtiss D12 Engines—Cylinder Head Construction—Valve Mechanism—Crankshaft—Crankcase and Oil Pan—Gearcase Assembly—Auxiliary Systems—Pistons and Connecting Rods—General Specifications, Low Compression—Tear Down Inspection, Curtiss D12—Disassembly Procedure—Propeller Hub—Carburetion Assembly—Gearcase and Ignition Assemblies—Cylinder Assemblies and Pistons—Oil Pan Assembly—Main Bearing Oil Tube—Main Bearing Caps—Camshaft Assemblies—Valves—Overhaul and Assembly—Top or Partial Overhaul—Crankcase—Crankshaft Assembly—Pistons and Piston Rings—Connecting Rod Assemblies—Oil Pan Assembly—Cylinder Blocks—Gearcase Assembly—Checking Valve Timing D12 Engine—Summary of Clearances.

Curtiss Water-Cooled Aviation Engines.—The Curtiss aircraft engines have been widely used and favorably known for many years and many record endurance, altitude and speed flights have been made with these motors. The popular and generally used OX5 series of war-time were succeeded by the K6 and K12 engines, the former having six cylinders and the crankcase cast in one block, the latter consisting of two K6 blocks mounted on one base in V form. Trouble was experienced in manufacture owing to the warping of the large castings so these engines were later redesigned to have the cylinder block and crankcase castings separate. Crankshafts were changed from four bearing to seven bearing and counterweights were eliminated. The remodelled K6 now known as the C6 is still built for commercial aviation service and delivers 160 horsepower and weighs 420 pounds. Several hundred of these engines are now in service and are far more reliable than the Model OX5, which has a good reputation in this respect. This six-cylinder engine weighs slightly less than the eight-cylinder OX5 and delivers 50 more horsepower. It is not geared.

The Curtiss D12 engine which is shown at Figs. 669 and 670 was designed and built in 1921 and passed its official 50-hour test in the beginning of 1922. This engine was the result of all the experience gained from the previous models and weighed 690 pounds, which was 30 pounds less than the Model CD12 engine. The bore and stroke were the same as in the latter, 4½ by 6 inches. The sparkplugs were relocated, one between the exhaust valve and the other between the intake valves, directly opposite each other. The carburetion was also greatly improved over that of the preceding models. All the detailed parts and accessories that had previously given trouble were altered and improved. More than 350 of these engines have been built and have developed an average of 410 horsepower at 2,000 r.p.m. and 440 horsepower at 2,250 r.p.m., low compression.

The Air Service has pushed the development of this engine steadily by running 50-hour tests at various speeds at McCook Field. The engine has passed 50-hour tests at 2,250 and 2,450 r.p.m., and developed 455 horsepower with low compression pistons in the test at the higher speed. Low compression is regarded as that compression ratio which will allow the

engine to operate without detonation on domestic aviation gasoline containing no "dope." This high-speed 50-hour test was run without any forced stops or trouble of any kind. The engine is now rated at 435 horsepower at 2,300 r.p.m. Operation for more than 200 hours between overhauls is being obtained in service with this engine.

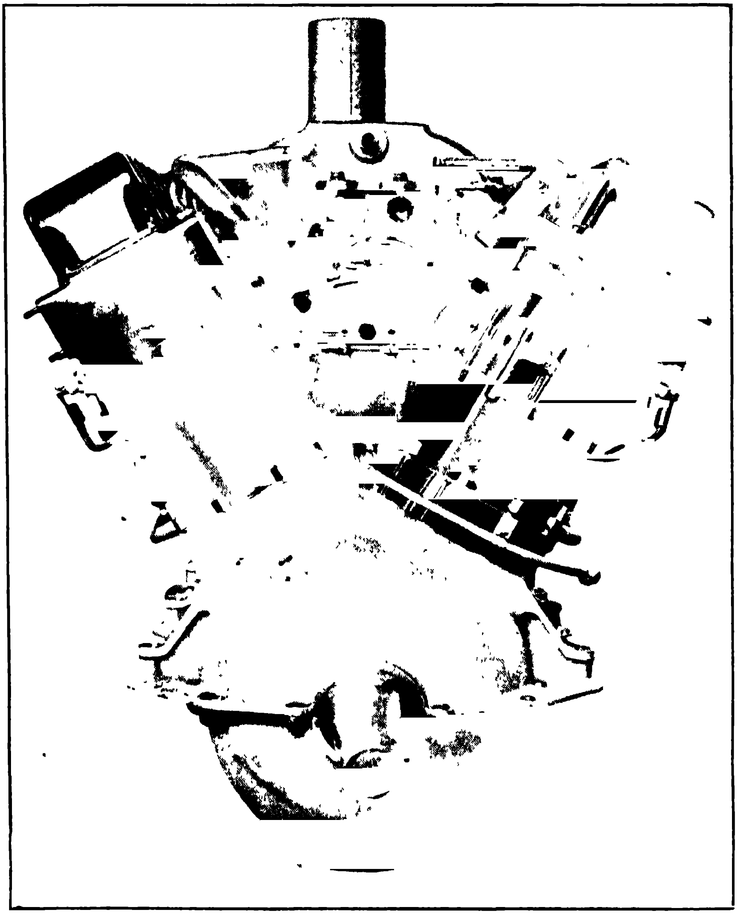


Fig. 669.—Direct Front View of Curtiss D12 Water-Cooled Engine.

Curtiss V-1,400 Engine.—During the latter part of 1924 the Curtiss V-1,400 engine, shown in Fig. 671 was designed and built. This model which has a bore of 4⅞ inches and a stroke of 6¼ inches develops from 505 to 520 horsepower at 2,100 r.p.m., low compression, and more than 600 horsepower at the higher speed and with high compression pistons. It is lighter than the production D12 engine, as it weighs only 685 pounds, dry and fits in the same engine bearers. It is slightly narrower than the D12 owing to the double camshafts being driven through three spur-gears in

tead of two, the bevel drive being attached to the third spur-gear, which s mounted below the two spur-gears on the ends of the camshafts. The sleeve construction is the same as in the D12 except that the heads of the sleeves are open and are screwed into the aluminum heads against shoulders on the sleeves. The valves are seated on aluminum-bronze inserts in the aluminum head. The cooling water comes in contact with the steel sleeves, as in the D12 engine, and the lower end of the sleeve is sealed with a composition gasket, as before. This cylinder construction is clearly hown at B, Fig. 166 in the discussion on water-cooled engine cylinder construction. Provision is made to use either battery or double-magneto

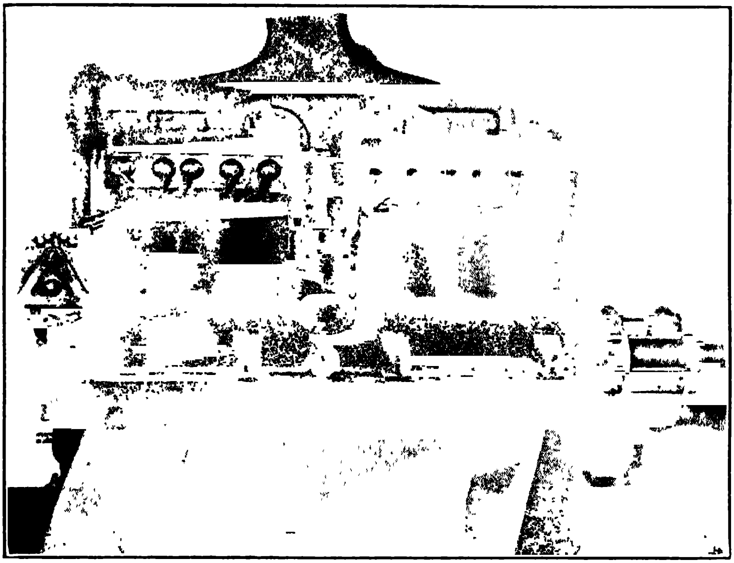


Fig. 669A.—The Curtiss Six-Cylinder Engine Model K6 Was One of the Intermediate Types.

ignition. The magneto is a Splitdorf double machine that operates with both armatures on one shaft and with two contact breakers, two coils and two condensers, all in the same machine. The distributors are mounted on the ends of the camshafts and are used with either the battery or the magneto ignition.

This V-1,400 engine, which weighs from 1.10 to 1.33 pounds per horsepower, depending on the power output, is more than 50 pounds lighter than its nearest competitor, either in this country or abroad. The simplicity and sturdiness of the crankcase will be noted in the illustration. During s official 50-hour test, which was completed in seven working days, the ngine improved in power throughout the test. The short duration of the st alone indicates the remarkable reliability of the engine. The new type f cylinder construction improved the valve cooling, as is indicated by the act that only three out of the 24 exhaust valves showed any leakage after he test. The average fuel consumption during the test was 0.49 pounds er brake horsepower hour. The average oil consumption was 0.018 pound

per brake horsepower hour, and the oil temperature difference between inlet and outlet was only from twelve to fourteen degrees Fahrenheit.

The small difference in oil temperature is most interesting, since a low oil temperature difference is highly desirable. With the production of very high horsepower in small units it is necessary to use an oil temperature regulating device in an airplane owing to the small crankcase area that is available for radiation. If the temperature difference is large, considerable heat must be dissipated, which presents a difficult problem. Air-cooling of oil has not been found satisfactory, since the oil in the cooler

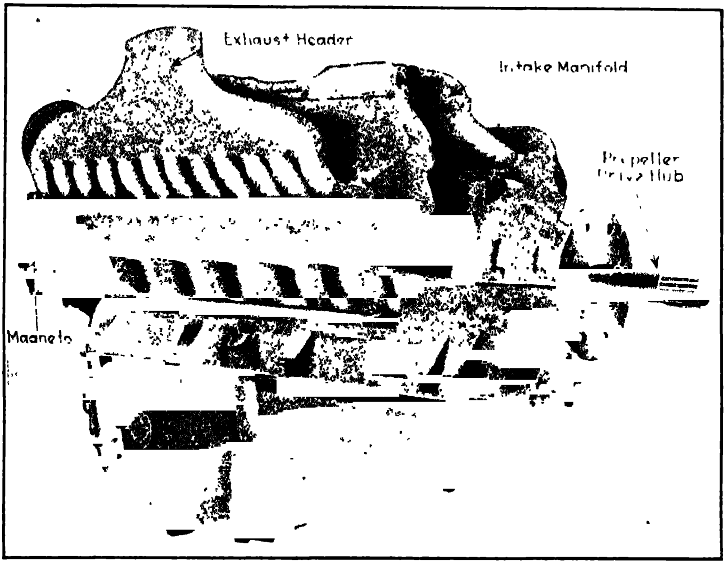


Fig. 669B.—Curtiss Twelve-Cylinder Engine Model K12 of Early Design.

congeals rapidly on the surfaces of the cooler and effectively insulates the remaining body of oil. As early as 1919 the Curtiss Company successfully adapted to its racing airplanes a method of oil-cooling by the use of the cooling-system water. A small-core radiator was inserted in the intake side of the water system. The oil was allowed to circulate through this core in the space usually provided for water in the conventional radiator, and the water was circulated inside of the cartridge tubes in the space ordinarily used for airflow. It was found that by this arrangement the oil temperature could be kept very close to the temperature of the water flowing into the engine, a very desirable arrangement.

CHARACTERISTICS V-1400

Length, overall	58¼"
Width, overall	26"
Height, overall	25¾"
Cylinders	12
Bore	4⅞"
Stroke	6¼"

Compression ratio	5.5 : 1
Horsepower	510 B Hp. at 2100 R.P.M.
Weight	660 pounds
Wt/Hp.	1.3 lbs/Hp.

Curtiss Conqueror Engine.—This is one of the most recent types and is shown at Figs. 672 and 673. It is made in direct drive and geared types, the side view at Fig. 673 being a geared type. It is rated at 625 horsepower

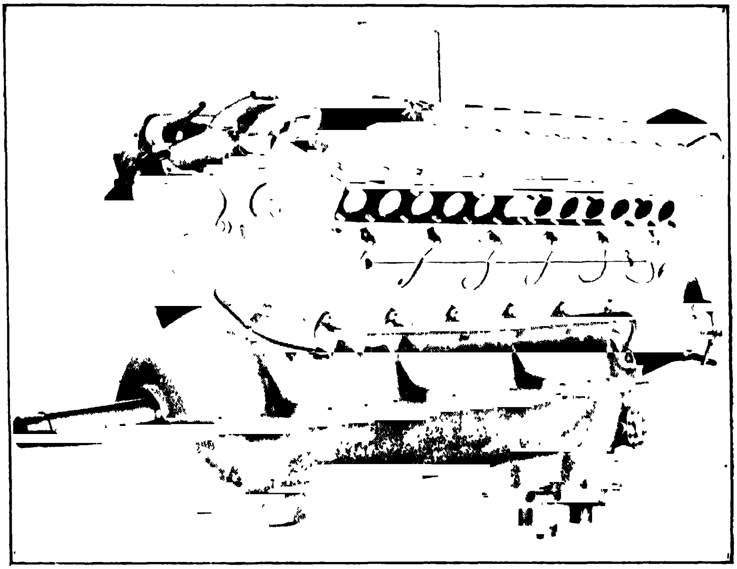


Fig. 670.—Curtiss D12 Water-Cooled Engine is a Light, Compact and Powerful Twelve-Cylinder Form. This is a Three-Quarter Front View.

at 2,400 r.p.m. The direct drive type is rated at 600 horsepower. It is similar in general construction to the famous Curtiss D12. The direct drive model weighs 760 pounds, the geared form weighs 840 pounds, these figures giving the dry weight without propeller hub or starter. The bore of the Conqueror is 5⅛ inches, the stroke is 6¼ inches. The compression ratio is 5.8 to 1. The brake mean effective pressure is 128 pounds per square inch. The displacement is 1,569 cubic inches. The overhead valve mechanism, cylinder construction and general arrangement is very similar to the D12 engine, the difference being in refinements of detail and of course, such changes in the structural elements as the larger power output and increased displacement makes necessary.

The 1,550 engines are designed to go in the same engine bearers as are used for the D12 engine. This means that the bearing areas on the new engines are not greater than those on the D12 as far as length is concerned. However, the crankshaft has been increased in diameter from three inches to three and one-half inches to take care of additional bearing area as well as to stiffen and strengthen the crankshaft for the additional power and speed. The details of construction of the crankcase,

crankshaft, and connecting rods are almost identical with those on the D12 engine. The connecting rod bearings are the same size but the ro have been increased in section in proportion to the power of the engine. Removable bearing shells are being used in these rods to facilitate service. Steel back bearing shells are being used on both the main and connecting rod bearings. The bearings in the forked rods are "Non-Gran" bronze. The bushings in the upper ends of the rods are also made of this material. The crankshaft is held in place with eight forged duralumin bearing caps which are mounted on the parting line of the crankcases, this line being on the center line of the crankshaft. The eighth bearing referred to is an out board bearing in front of the thrust bearing on the direct drive engine and in front of the pinion reduction gear on the geared engine.

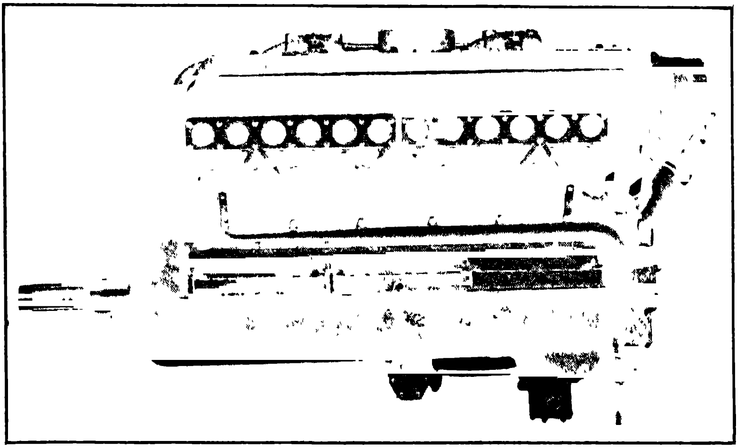


Fig. 671.—Side View of Curtiss V-1400 Aviation Engine which Delivers 510 Horsepower at 2,100 R.P.M. and with a Dry Weight of 1.3 Pounds per Horsepower.

The cylinder block construction differs from the D12 in the cylinder sleeve and valve seat arrangement. The D12 has a closed end sleeve with the valves seating in the closed steel end. The 1,550 models use a sleeve open at both ends and screwed into the aluminum head. The valves seat on aluminum bronze inserts. This type of construction was developed in the V-1,400 engines which had a bore and stroke of 4⅞ inches by 6¼ inches, respectively, while this engine has a bore and stroke of 5⅛ inches by 6¼ inches. This type of valve seat construction is being used in many air-cooled engines with aluminum heads. The valve size has been increased to take care of the increased displacement, this being possible on account of the larger cylinder bore. The Curtiss valve gear using the "T" shaped cam-followers and double camshafts is retained on this model although two of the camshaft bearings on each head have been eliminated to save weight.

The conventional type water cooling system is used, a centrifugal pump feeding the two cylinder blocks at the lower end of the jacket at six points from two outlets on the pump. The water leaves the topmost point of the head from six points on each head, entering a manifold from

which it can be conducted either to a radiator or through a water expansion tank and then to a radiator.

The lubricating system is the same as on the latest production D12 engines. One pressure pump feeds oil directly to the main bearings through an oil manifold attached to the top of the bearing caps. The oil passes into Nos. 2, 4 and 6 main bearings, each of these main bearings feeding two connecting rods through steel tubes spun into the crankshaft. An annular groove cut into the babbitt of each connecting rod bearing insures pressure feed to the link pin bearings. The piston pin bearings are fed by the oil

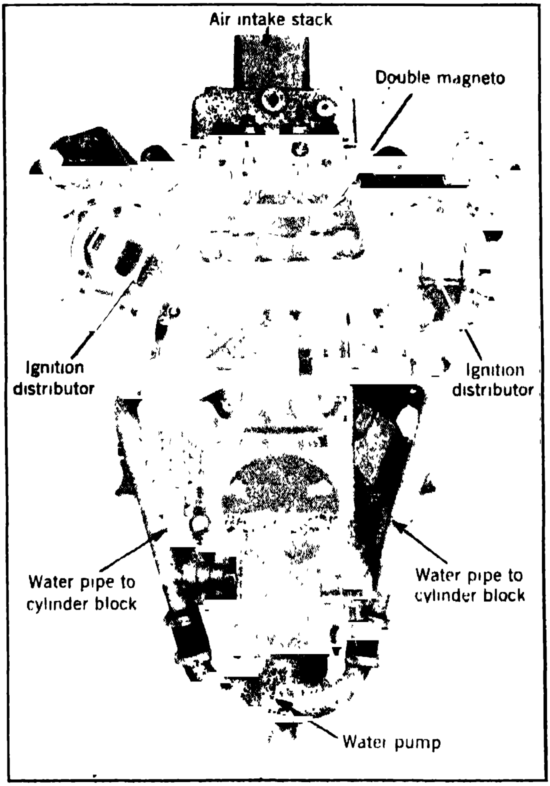


Fig. 672.—Anti-Propeller End View of the Curtiss V-1570 "Conqueror" 625 Horsepower Direct Drive Twelve-Cylinder Water-Cooled Engine.

which is thrown into the cylinders from the crankshaft. By means of a tube spun into No. 1 main bearing at the accessory end of the engine, oil is indexed through steel pressure tubes to the camshaft bearings. The backs of the cams are drilled for lubricating the "T" shaped cam-followers. Oil is also fed from this same line to the plain bearings on the upper vertical shaft. The plain bearings on the lower vertical shaft are fed by oil which collects in a large pocket around these bearings. The oil draining from the camshaft bearings lubricates the ball bearings on the camshafts, driveshafts

as well as the ball bearings on the upper end of the water pump shaf· The oil is returned to the outside oil tank in the following way: there are two scavenging pumps. One takes oil from the propeller end of the engine and delivers it to the accessory end of the engine or the back end of the engine when it is installed in an airplane. The second pump picks up the oil from the back end of the engine, returning it to the outside oil tank By the use of this system, any air which is picked up by the propeller end pump when the engine is in a climb will be discharged into the crankcase, thereby, eliminating practically all foaming of oil in the tank caused by emulsion of oil and air.

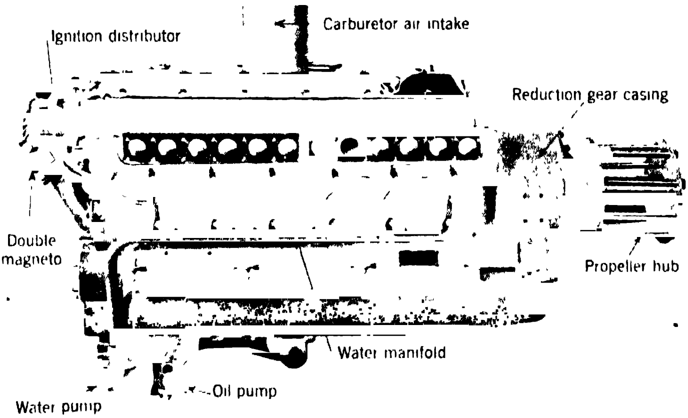


Fig. 673.—Side View of the Curtiss V-1570 "Conqueror" Engine with Geared Propeller Drive.

The GV-1,550 engine is a geared model, being built at the present time with a gear ratio of two to one, the propeller turning at half engine speed. Regular stub tooth spur gears with a three-inch face width are used. The large gear is mounted on a Curtiss flexible coupling which absorbs the shocks in the gear train insuring long life. After a 50-hour test at 525 to 535 horsepower, these gears showed no wear, being in practically the same condition as when the test started. The propeller shaft is mounted on plain bearings with the outer bearing in a housing which bolts to the crankcase The main housing is cast integral with the crankcase. Thrust is taken on a large deep grooved ball bearing. The bearings on each side of the pinion are also plain, the end thrust of the crankshaft, due to its weight when in an inclined position, is taken care of by a small deep grooved ball bearing mounted in a cap which closes the hole in the crankcase at the end of the crankshaft. This bearing also locates the position of the crankshaft in the case. In the direct drive model the crankshaft is held in position by th deep grooved thrust ball bearing located between Nos. 7 and 8 main bearings, being similar in construction to the D12 engine.

The geared engine passed a 50-hour official Government test at 5[illegible] horsepower at 2,100 r.p.m., and, as a result of subsequent testing a[illegible]

higher speeds, has been developed for use at 575 horsepower at 2,500 r.p.m. The direct drive model has been developed for use at 600 horsepower at 2,500 r.p.m. The direct drive model was used in one of the 1925 Schneider Cup Races also when it was flown in the 1926 race. The engine developed, with high compression, a maximum of 708 horsepower at 2,600 r.p.m. and weighed 725 pounds dry. The geared model weighs 840 pounds dry, which gives an additional weight of 115 pounds due to the gearing. The D12 engine weighs 680 pounds. Therefore, by the addition of 35 pounds in weight, it has been possible to increase the power by approximately 150 horsepower with a slight reduction in frontal area. This reduction has been possible by the use of three spur gears driving the double camshafts, the third spur being placed as an idler below the two gears on the camshafts. The bevel driving gear is mounted on this third gear. This design drops the bevel gear behind the cylinder block, thereby taking off approximately two inches in width at the back end of the engine. The engine has a maximum width, as a result of this change, of 26 inches, whereas the D12 is 28 inches wide.

It might be well to point out that a normal engine speed of 2,500 r.p.m. is something like 500 r.p.m. higher than any air-cooled engine of anywhere near this power. During violent maneuvers in pursuit planes, the engine speed in a vertical drive reaches something over 3,000 r.p.m. No air-cooled engine of radial form, as far as the writer knows, has been made to withstand this severe speed. The advocates of radial engines for pursuit airplanes must face the fact that these high speeds are not as easy to obtain with the heavy crankpin loads as they are in Vee type engine with lighter loads. The gasoline engine, particularly with a supercharger, increases its power almost directly in proportion to the engine speed. Therefore, it is very advantageous to use this speed and the Vee type of engine, either water-cooled or air-cooled, undoubtedly has an advantage in this respect. Also, other types of engines which are a compromise between the radial form and the Vee form are undoubtedly superior in respect to the heavy crankpin loads than is the radial engine.

The air-cooled radial appears to be the lightest form of engine per horsepower at a given speed. However, it is not the best form as far as head resistance is concerned, owing to its large overall diameter, as has been demonstrated by the comparative performance of the Curtiss Hawk airplane with the Liberty air-cooled Vee engine and a radial air-cooled engine of the same power. The machine was faster and the visibility better when using the Liberty air-cooled engine. By using high engine speeds which are at present prohibitive in the pure radial type of engine, the water-cooled and air-cooled Vee engines can compete with the radial on a basis of weight per horsepower, although at the present time the specific weight is in favor of the air-cooled radial on some of the new engines starting in production, which, however, have not been service-tested extensively. While it has not been definitely proved that the radial form of engine, with its heavy crankpin loadings, cannot be run at such high speeds as 3,000 r.p.m. or more, the fact remains that it has not been done nor is there any record of the makers of such engines recommending speeds in excess of 2,200 r.p.m. for geared forms. With more cylinders

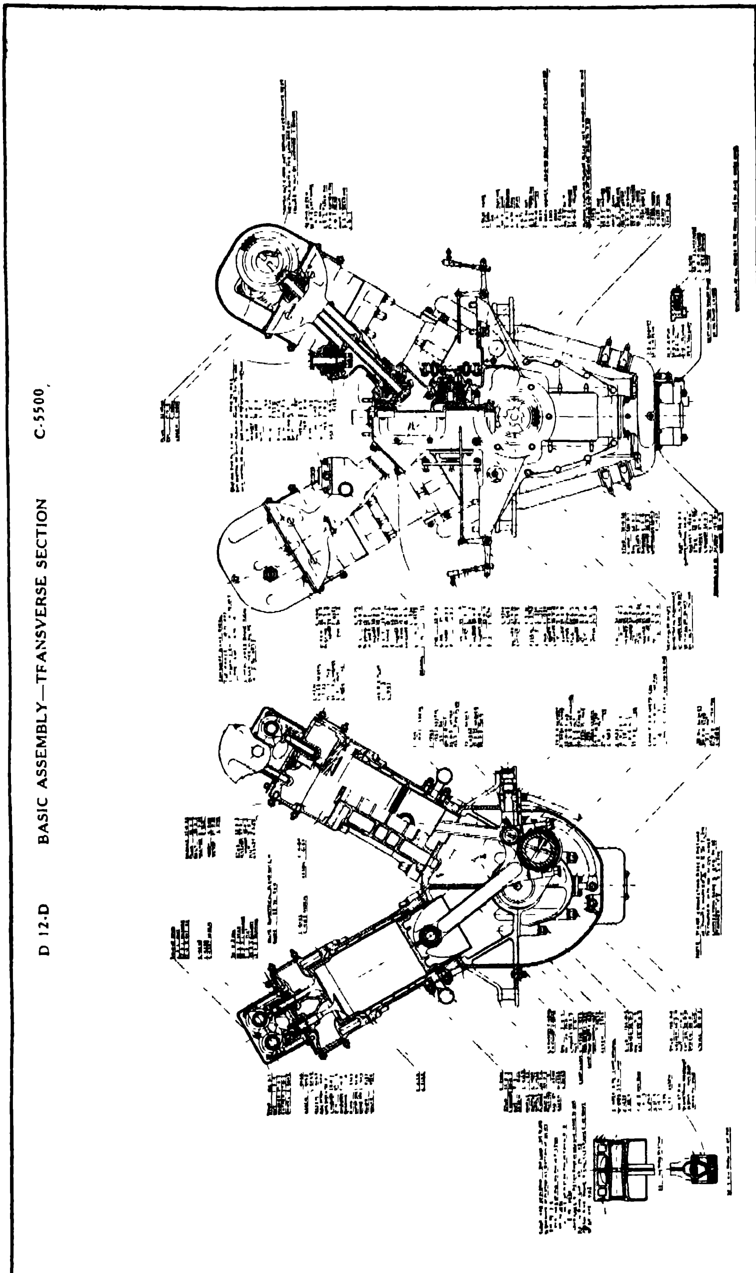


Fig. 674.—Basic Assembly—Transverse Section of Curtiss D12D Aviation Engine.

of smaller size and with the knowledge that is available at the present time, the cooling ability of an air-cooled engine is definitely limited by the amount of square inches of cooling fin that can be put on a given volume of cylinder. Therefore, if the horsepower goes up in direct proportion to the speed there will be a definite engine speed at which the air-cooled cylinder will not cool. With a water-cooled engine one needs only to supply more radiation to take care of the increased horsepower. The use of such engine speeds as 5,000 to 7,000 r.p.m. in racing car engines gives one an idea of the possibilities of further development with the water-cooled type. It is very doubtful whether it will be possible to get the horsepower per cubic inch out of an air-cooled engine at these high speeds unless some radical development in cooling is made, providing of course, that no other limiting factors, such as propeller efficiency holds the speed down.

Curtiss D12 Engines.—All Curtiss D12 type engines are rated 435 horsepower at 2,300 r.p.m., regardless of model numbers such as D12C, D12M, etc. The Curtiss D12 aircraft engine is a twelve-cylinder, water-cooled 60 degree Vee type engine employing two high-tension magnetos and two dual carburetors. The cylinder construction is of the enbloc type, with cylinders of the wet sleeve type four and one half inches bore by six inches stroke, or a total nominal displacement of 1,145 cubic inches. There are four valves per cylinder, two inlet and two exhaust. These valves are operated by two camshafts on each cylinder head driven by bevel gears of the timing gear train. Each water jacket serves six cylinders and transmits the explosion forces to the crankcase.

Cylinder Head Construction.—Steel cylinder sleeves of carbon steel hydraulically forged with one end closed are rough machined, heat-treated, and finished-machined with the exception of the final grinding of the bore before assembling in the cylinder head. The threaded portion of the sleeve is approximately one and one half inches long, and is at the closed end. Careful machining is done on these sleeves and the cylinder head to maintain a perfect joint between the aluminum alloy head and the steel sleeve. An integral stud on the end of the closed head of the sleeve passes through the water jacket thereby improving the contact between the steel head and the aluminum head. The valve port holes are machined after the sleeve is assembled and duralumin sparkplug bushings are assembled in place. The aluminum water jacket is cast in one piece and is assembled over the lower end of the six sleeves, the water joint being maintained between the sleeve and jacket by a composition gasket under the flange on the sleeve. The upper joint is made tight with a copper asbestos gasket. The sleeves fit very snugly in the water jacket at the lower end. This gives ample support to prevent the thin sleeve from going out of round. The cylinder head is NOT REMOVABLE. The basic assembly views at Figs. 674 and 675 show the construction of the engine and should be referred to as the description is read.

Valve Mechanism.—Each cylinder is fitted with four interchangeable steel tulip valves, two intake and two exhaust, seating directly in the steel cylinder head. The valve stem guides are cast iron. The camshafts are mounted on the top of the cylinder heads on six aluminum brackets, the shafts running directly in the aluminum. These brackets are carefully

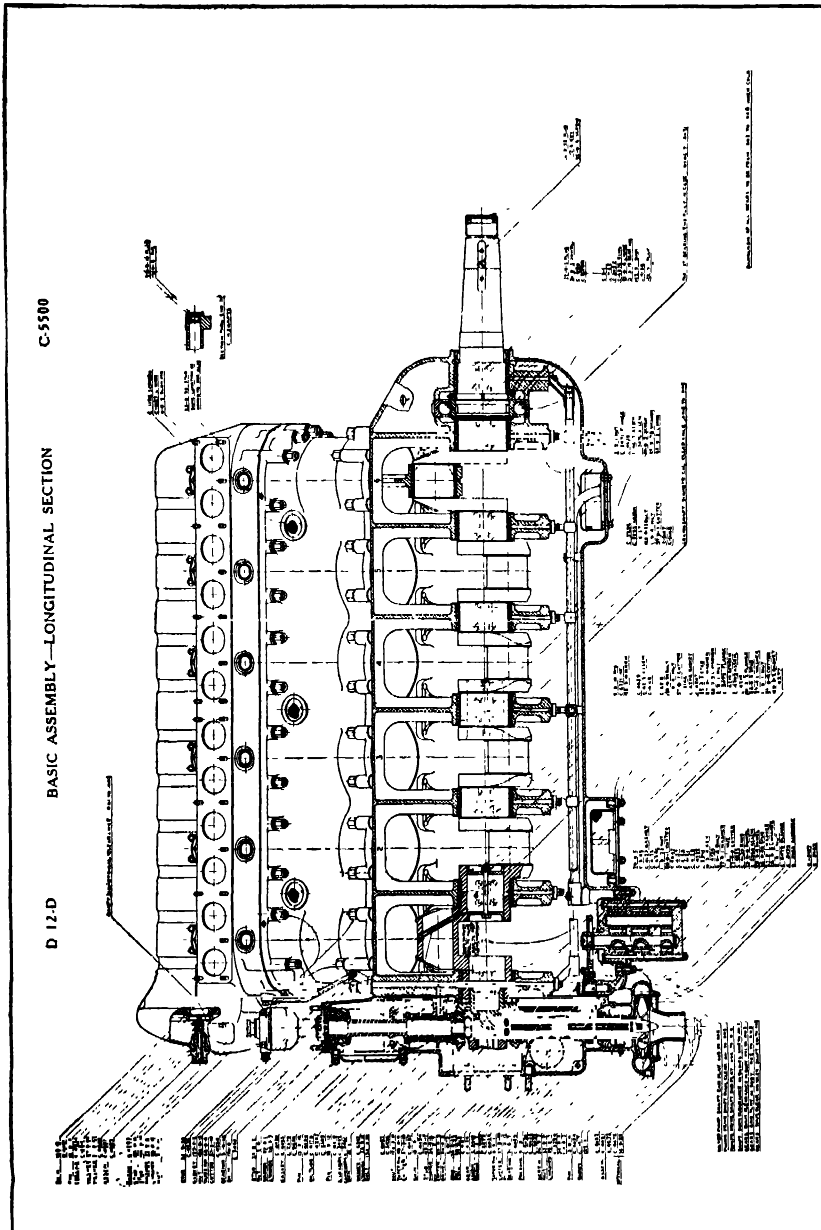


Fig. 675.—Basic Assembly—Longitudinal Section of Curtiss D12D Aviation Engine.

doweled to the head and are interchangeable, no alignment, reaming or hand scraping being necessary during manufacture or overhaul. The intake camshaft is driven by the exhaust shaft by means of spur gears at the anti-propeller end. A bevel gear is mounted on the exhaust camshafts as follows:—The spur gear on the exhaust shaft is extended beyond the width of the normal gear and the bevel gear is internally splined to fit over this extension. A single large flanged nut holds this gear on the shaft. Owing to the fact that the number of teeth on the spur gear differs from the number of teeth in the bevel gear a very fine adjustment is obtainable on the timing by shifting the gear in relation to the shaft. One cam operates two valves through a Tee shaped cam follower working in a bushing in the cylinder head, the cam follower removing all side thrust from the valve stems. The valves are adjusted by adjusting screws clamped in the ends of the Tee cam follower. The camshaft bearings are lubricated by oil pressure of approximately six pounds per square inch and the cam followers and valve guides are oiled by splash.

Crankshaft.—The crankshaft is of the conventional eight bearing type being made of low chrome nickel steel. The center journal is one and three-quarter inches effective length and the balance of the journals one and one-half inches. The journal and crankpin diameters are three inches and two and one-half inches respectively and the crank cheeks are oval in profile. The propeller thrust bearing is mounted between No. 7 and No. 8 main bearings and is a deep-grooved radial annular ball bearing. This bearing takes thrust in either direction and the method of mounting adds greatly to the rigidity of the propeller in flight. Gyroscopic forces are well taken care of by this arrangement. The crankshaft and its bearings are clearly shown in longitudinal section, basic assembly drawing at Fig. 675.

Crankcase and Oil Pan.—The crankcase is an aluminum alloy casting divided into sections by the webs supporting the main bearings. There is a pocket in the case between No. 7 and No. 8 main bearing for the thrust bearing. Each bearing cap is held by four studs and castellated nuts and is located positively by a key and keyway. The bearing caps are duralumin forgings, all the same except for No. 7 and No. 8 which locate the thrust bearings. Oil is fed to the main bearings through drilled passages in the bearing caps as shown at Fig. 675. A passage is machined in the right hand side of the crankcase at the center web for receiving a thermometer for indicating the inlet oil temperature and is also an oil duct to the main bearing oil manifold.

Steel-backed babbitt bearing shells are used for both main and connecting-rod bearings. The main bearing shells are held in place in both the caps and case by four brass countersunk head screws and by the clamping action of the bearing caps. The bearings are bored and burnished to size in a boring mill by means of a fly cutter boring bar. This method of machining insures correct diameter and alignment.

The oil pan is an aluminum alloy casting supporting the oil pumps and incorporating the chamber for the oil strainer. The idler gear between the lower vertical shaft (pump shaft) of the gearcase and the oil pump drive gear is also supported by the oil pan. There are two small sumps in

the oil pan, one at the propeller end and the other where the oil pumps are assembled.

Gearcase Assembly.—The gearcase assembly which is shown at Fig. 676 is removable as a unit and comprises drives for fuel, oil and water pumps, magnetos, gun controls, camshafts and generator. There are two vertical shafts as shown in the illustration of the timing gear train at Fig. 677, the lower driving the water pump by means of a spline, the fuel pump by a worm drive and the oil pump by spur and idler. This shaft

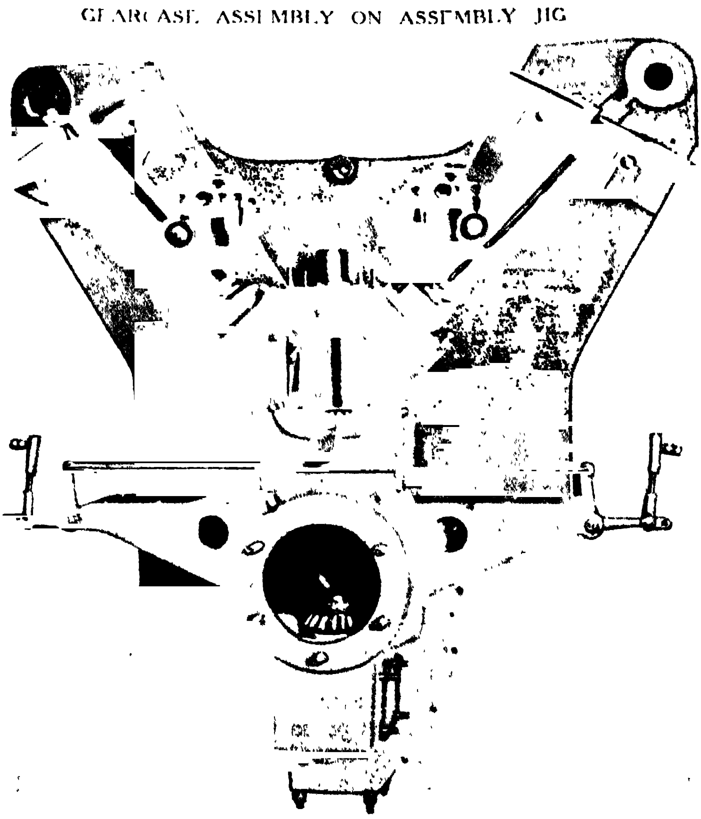


Fig. 676.—Curtiss D12 Gearcase Assembly on Assembly Jig, a Shop Fixture that Insures Proper Alignment of Parts.

runs in two bronze bushings which are lubricated by the oil bath in which the shaft is located. A pocket of about one-half a pint capacity is incorporated in the gearcase casting around this shaft and is filled by the oil draining from the camshaft housings. The shaft is driven at one and one-half engine speed by a bevel gear at its upper end meshing with the crankshaft gear. The spur gear at the bottom end of the shaft is below the pocket and drives a spur idler, this in turn driving the oil pumps. Lubri-

cation is by oil collecting in the sump the oil pumps are located in. The upper vertical shaft runs in bronze bushings, one at the lower end and one just under the shoulder near the center of the shaft, and has a ball bearing at its upper end. There is a small annular space between the bushings, and this is supplied with oil under pressure. The ball bearing is lubricated by splash. The shaft is driven by the crankshaft gear and a bevel gear at one and one-half engine speed.

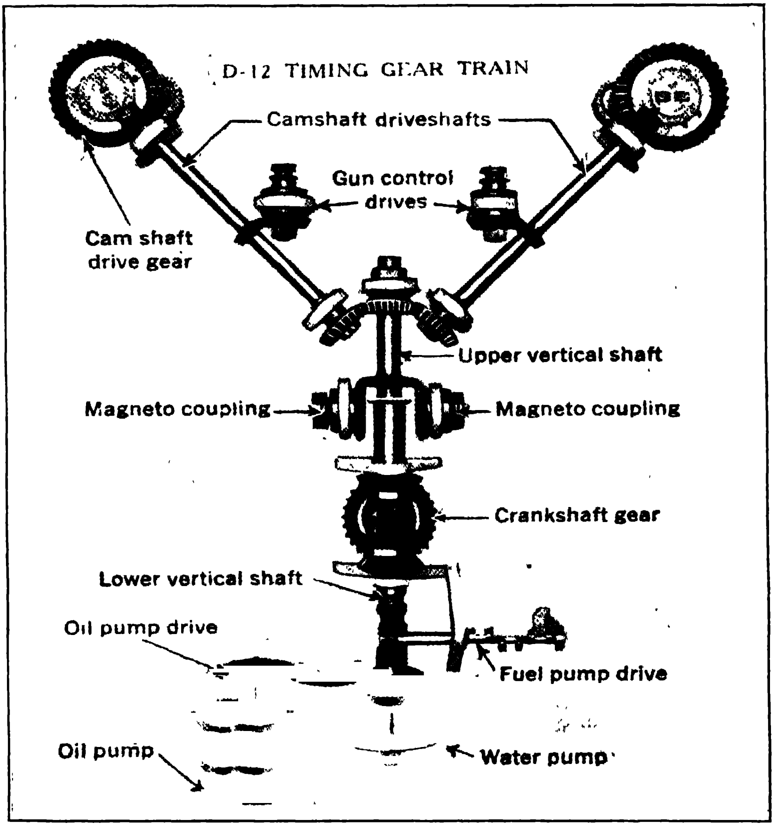


Fig. 677.—The Timing and Accessory Drive Gear Train of the Curtiss D12 Aviation Engines.

Just above the shoulder there is a bevel gear driving the magneto couplings through bevel gears, one coupling on each side of the gearcase. The magnetos extend at right angles to the longitudinal axis of the engine, being mounted on brackets cast on the gearcase. Both magnetos rotate the same. The magneto coupling drive consists of a combination of an Oldham coupling and a Thermoid disc, thus taking care of slight misalignment and providing a shock absorber. A micrometer adjustment is obtained by the use of two discs having a different total number of holes on equal pitch circles.

At the upper end of the shaft under the ball bearing is an angle gear meshing with the angle gear at the lower end of each camshaft driveshaft These gears are all the same pitch diameter. The camshaft driveshafts rotate at one and one-half crankshaft speed and drive the bevel gears of the exhaust camshafts by means of small bevel gears at their upper ends. The gears are splined internally and fit over splines on the shafts. Castellated nuts hold the gears tightly and are locked by taper pins. All adjustments are by means of steel shims of different thicknesses. The gun control drives are mounted on the housings for the camshaft driveshafts and revolve at crankshaft speed. There are two ball bearings in the gun control drive housings, the bearings, shims, and gear being clamped in place by a castellated nut on the end of the shaft. The gear driving the gun control is machined in the camshaft driveshaft.

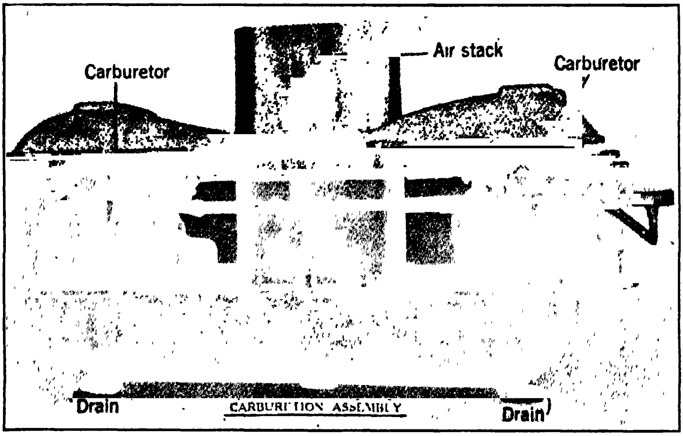


Fig. 678.—Carburetion Assembly of Curtiss D12 Aviation Engine.

Auxiliary Systems.—Two Stromberg NA-Y5D or NA-Y5F carburetors are used. Each carburetor is connected to a "Y" manifold, this in turn being connected to an "L" manifold on each cylinder block. Each carburetor barrel supplies three cylinders. The "Y" manifolds are water jacketed. Both carburetors are supplied with air by a single air scoop and air chimney. The carburetors, air scoop, air chimney and "Y" pipes may be lifted as a unit. (Fig. 678.) Two Scintilla AG-12D (or VAG-12D) or Splitdorf SS12 magnetos are used for ignition on the engine, supplying two sparkplugs per cylinder. The left magneto fires the plugs located at the intake side of the cylinder blocks and the other the plugs at the exhaust side.

Water is taken in at the bottom of the water pump and discharged into a distributing manifold at the lower part of each water jacket. The water is passed upwards to the cylinder head and taken from the head by manifold or header fastened directly to the head. Connections are mad

from the surge or expansion tank and the inlet water pipe to the "Y" manifold jackets. This engine has been designed to use water manifolds for the outlet directly on the cylinder head thus eliminating the objectionable feature of passing water through the intake manifold gasketed joint. The water system as supplied on the engine should not be altered. The conventional pressure and dry sump lubricating system is used on this engine. The scavenging pumps are entirely separate, eliminating any possibility of air destroying the pump capacity. All plain bearings are pressure fed except the bushings for the lower vertical shaft of the gearcase. All other bearings are splash fed by the oil running back from the camshaft housings.

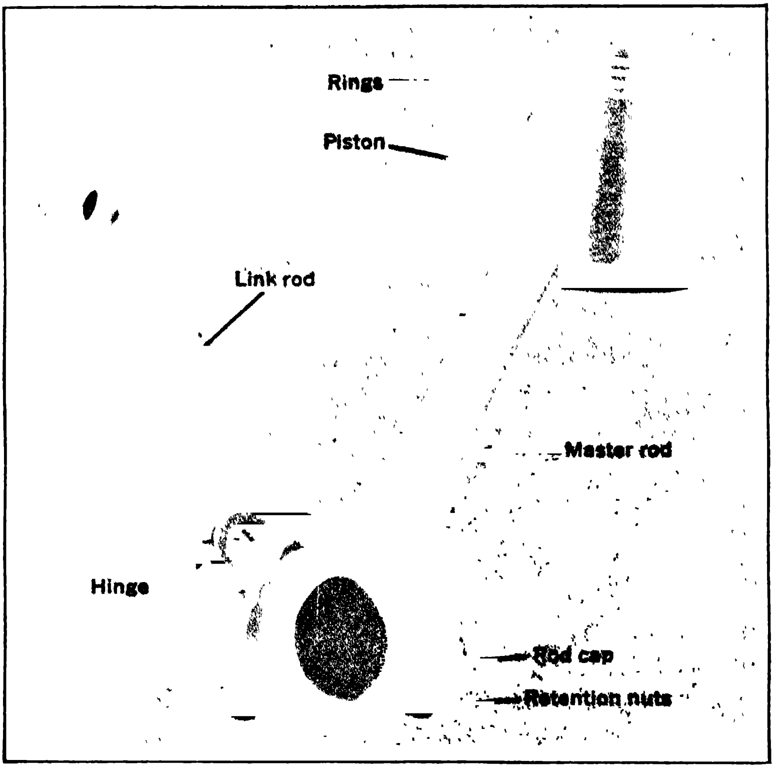


Fig. 679.—Connecting Rod Assembly of Curtiss D12 Aviation Engine.

Pistons and Connecting Rods.—The pistons are aluminum alloy castings of the ribbed head type, this construction allowing a light, strong piston. All rings are $\frac{3}{32}$ of an inch wide. The piston pins float in both the pistons and the connecting rods and are held in place by lock rings in the pistons. Oil holes just below the lower ring allow the excess oil to be removed from the cylinder walls. The connecting rods are of the master and articulated type as shown at Fig. 679. Both rods are steel drop forg-

ings machined all over. The piston pin bushings are of bronze and are pressed in. They are lubricated through two 5/16-inch diameter holes near the top of each rod. The wristpin bushings are also of bronze and are lubricated by pressure from the crankshaft. The wristpin is held in its proper place in a boss on the master rod by a bolt and nut.

The fuel system used on the D12 engine employs the Curtiss Triplex or the Air Corps C5 gasoline pump feeding fuel to the carburetors. The over capacity of the pump is taken care of by a relief valve and an overflow back to the tank. Various models of D12 engines are made, these differing in details but all are the same in construction of the principal

GENERAL SPECIFICATIONS

Low Compression

Name	Curtiss
Rated Hp.	435 Hp. at 2300 R P M
Model	D12D
Type of Engine (Direct Drive)	Water-Cooled "Vee"
Number of Cylinders	12
Length of Engine	56¾"
Width of Engine	28¼"
Height of Engine	34¾"
Displacement of Engine	1145 cu. in.
Bore	4 5"
Stroke	6"
Compression Ratio	5.3 to 1
Type of Piston	Aluminum trunk ribbed
Piston Displacement	95 4 cu. in.
Number of Piston Rings	3 per cylinder
Angle of Cylinders	60°
B.Hp. at sea level at 2300 R P M. (Maximum)	450
Ignition System, Scintilla or Splitdorf	Two single spark high-tension magnetos
Carburetor (Type and Size)	Two 2" Stromberg NA-Y5D or NA Y5F
Number of Main Bearings	8
Type of Oil Pump	Gear
Desired Oil Temp under normal operation, inlet	140° F.
Oil pressure desired (Minimum with oil outlet at 160° F.) at 2300 R P M	120 lbs per sq in. ga.
Grade of oil desired	Winter, Gulf 75-85; Summer, Gulf 90-95
Average oil consumption per B Hp. Hr.	.010 lb.
Type of Water Pump	Centrifugal
Maximum water temp allowed	180° F.
Capacity of cylinder water jackets	44 lbs.
Average fuel consumption per B.Hp Hr. Full Throttle	.52 lbs.
Average fuel consumption per B Hp Hr Cruising	.50 lbs.
Pressure of fuel supply	3 to 5 lbs. per sq. in. ga.
Speed of Propeller	Crankshaft
Speed of Tachometer Shaft	½ Crankshaft
Firing Order	1L-6R-5L-2R-3L-4R-6L-1R-2L-5R-4L-3R
Approximate hours before overhaul	200
Weight of Engine empty and without accessories	680 lbs. plus or minus 10 lbs.

parts and the main assembly. The general specifications of the low compression type or D12D engine may be considered typical and these refer to the engine shown in sectional views at Figs. 674 and 675. The installation drawing at Fig. 680 shows important dimensions.

Tear Down Inspection, Curtiss D12.—This engine does not have a removable head. The cylinder blocks (banks) are removable as complete units. The joint just below the sparkplugs is merely the place where the water jackets attach to the cylinder head assembly. This joint should never be disturbed as removing and replacing the water jacket without proper equipment may cause the lower end of the cylinders to go "out of round." When the observer looks over the anti-propeller end of the engine toward the propeller end everything to the left of the vertical plane through the center line of the main bearings is referred to as being on the left hand (L.H.) side. Keep all parts clean. If the parts are not to be worked on immediately cover the steel parts with light grade Corol or other rust preventing compound. It is recommended that each assembly be removed as a unit and be kept as such until ready for the overhaul of that unit. Overhaul each unit separately.

Disassembly.—If it becomes necessary to completely disassemble the engine for reconditioning it is recommended that the following order be carried out. 1. Remove the exhaust sparkplugs. 2 Remove the propeller hub. 3. Remove the carburetor assembly. 4. Remove the intake sparkplugs. 5. Remove the cylinder head covers. 6 Remove the inlet water tubes, loosen the gearcase assembly, and remove the distributor blocks.

7. Remove the gearcase assembly and crankshaft gear. 8. Remove the ignition wires and conduits. 9. The magnetos should be removed from the gearcase, tested, and put in first-class condition. 10. Remove the camshaft oil supply tube from the crankcase and cylinder blocks. Remove the R. H. cylinder block (bank) from the engine, taking care to prevent pistons and rings from being damaged. 11 Remove the R. H. pistons from the connecting rods. 12. Remove the L. H. cylinder block taking care to prevent the pistons and rings from being damaged. 13. Remove the pistons from the master rods.

14. The oil pan assembly should be removed. 15. The main bearing oil tube should be carefully removed before attempting to remove the main bearing caps. 16. The connecting-rod bearing caps should be taken off and the connecting-rod assemblies taken out. 17. The main bearing caps should be taken off and the crankshaft removed from the engine. 18. The camshaft assembly should be taken off each cylinder head. 19. The valves should be tested and taken out of the engine.

Exhaust Sparkplugs.—The sparkplugs should be taken apart (after noting their general appearance) using the special B. G. wrench and holder if possible. If necessary the plugs should be cleaned thoroughly with gasoline and a stiff brush. The carbon deposit on the mica core should be removed with fine sandpaper. Care should be taken to prevent getting the shells and cores mixed. When assembling, be sure the core is screwed into the shell very tight. For AC plugs the gap should be .023 inch and for BG plugs .015 inch. All plugs should be tested with a high-tension

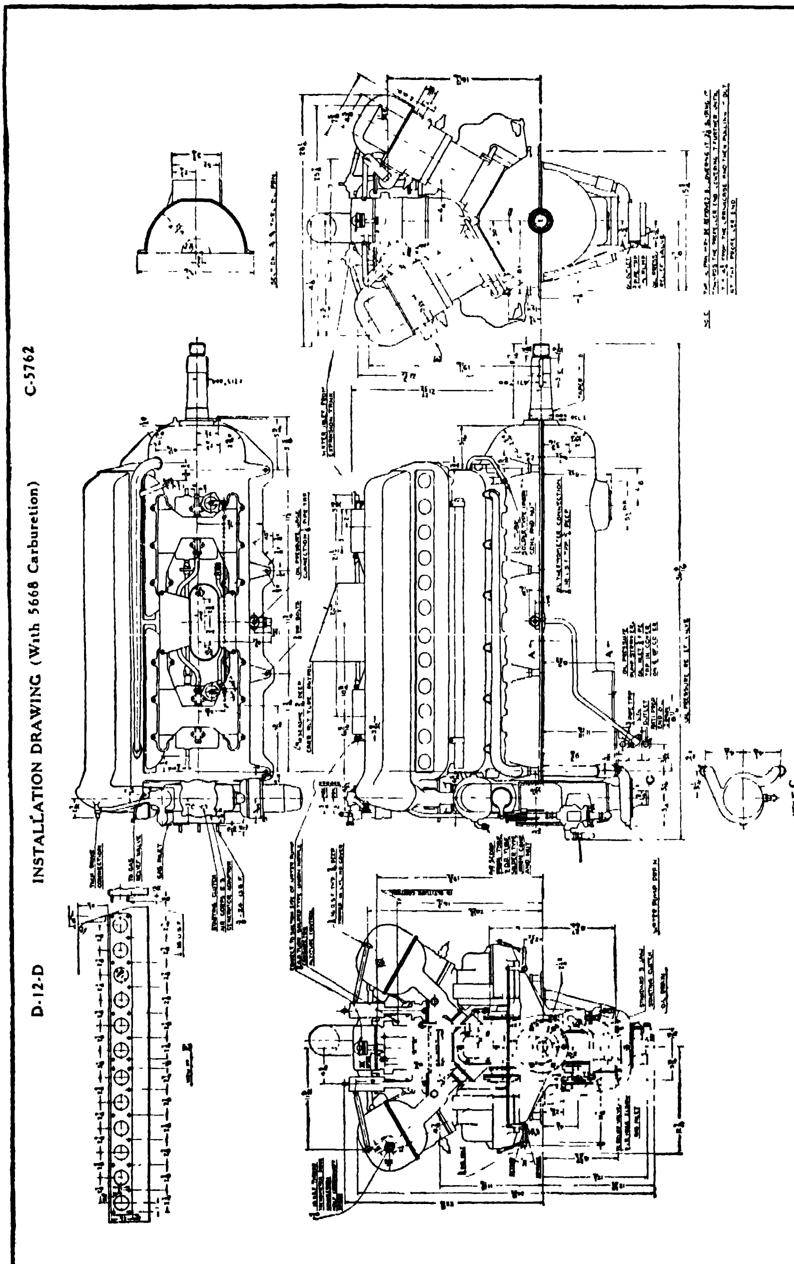


Fig. 680.—Installation Drawing of Curtiss D12D Aviation Engine.

electric current before replacing in the engine. If tested with a vibrator coil spark in the dark, any leakage between core and shell can be readily determined.

Propeller Hub.—The propeller hub may be removed by using a four foot bar one and one-quarter inches diameter. This bar should have one or both ends turned down to a diameter of seven-eighths of an inch for a distance of three and one-quarter inches from the end. The propeller hub nut has a right hand thread. In backing off the propeller hub nut it will be noticed that the first turn will be easy but then the nut will turn hard. By using a heavy hammer to strike the bar close to the nut and in the meantime keeping a tension on the bar, the nut will loosen quicker than by applying only a steady pull on the bar. The hub nut has different threads and the nut acts as a puller when unscrewed. Screw the hub nut by hand on the end of the crankshaft to prevent damage to the threads of the crankshaft in event of an accident in handling.

Carburetion Assembly.—The NA-Y5F carburetor assembly as shown at Fig. 678 may be removed after removing the air chimney and disconnecting the throttle, altitude controls, and fuel lines by simply disconnecting the "Y" pipes from the "L" manifolds. The two carburetors, the "Y" pipes and the airscoop will lift off as a unit. For removing the NA-Y5 carburetor assembly the interconnecting altitude control rod must be removed first. Intake Sparkplugs.—The intake sparkplugs may be removed from the Vee of the engine and cleaned and inspected as previously mentioned for exhaust plugs.

Cylinder Head Covers.—The cylinder head covers are fastened by means of fillister head cap screws. Before the screws are removed, the tachometer drive assembly should be taken out as the cover is not removable with this assembly in place. After removing the cap screws the covers may still refuse to come entirely clear. This is due to the fact that in certain positions there is not enough clearance between the cams and the cover. By turning the crankshaft slowly the cams will clear and the cover will lift off. Do not turn the crankshaft while the cover is held up from the gasket surface as a turning cam may spring the cover.

Gearcase and Ignition Assemblies.—Disconnect the hose connections between the water pump and the inlet water tubes and remove the water tubes (manifolds). The gearcase should not be removed until after the position of the timing marks is noted. The arrows on the magneto couplings should line up with the scribed line on front of the gearcase when the breaker points on the L. H. magneto break to fire cylinder 1L (one left). The magneto coupling gear marks should line up when the central mark on the gear of the upper vertical shaft is at the center of the upper opening. In this position all timing marks should line up according to drawing -4,650 (Fig. 681).

The gearcase as shown at Fig. 676 is held on the engine by cap screws and nuts. There are two cap screws holding each housing for the camshaft driveshaft to the cylinder block. The gearcase should be removed as unit. After removing the screws and nuts holding the gearcase on the engine pull the gearcase away from the engine about two inches. This

will allow the removal of the inside distributor blocks of the Scintilla magnetos. When equipped with Splitdorf SS12 magnetos the distributor blocks may be removed without loosening the gearcase assembly. Remove the gearcase and the crankshaft gear from the engine. The ignition wires conduits, and distributor blocks may be removed as a unit. The conduits are held to the cylinder blocks by aluminum clips. Do not remove the wires from the conduits or the distributor blocks as it is not necessary.

Magnetos.—The magnetos may be taken off by disconnecting the spark control rods and removing the four dural cap screws holding the magnetos to the gearcase. The R.H. and L.H. assemblies bear identification marks but great care should be taken to prevent the different parts from becoming mixed.

Cylinder Assemblies and Pistons.—It is not necessary to remove the intake "L" manifolds, but care should be used to prevent them from being damaged. The R H. cylinder block should be removed first. If there are a number of mechanics available it is advisable to turn the engine so that the right hand block is horizontal. There should be at least three mechanics to remove each cylinder block, one supporting each end of the block while removing it and the other to prevent the pistons and rings from being damaged If there are only two mechanics to do the work light chain falls should be used to lift each cylinder block off. Turn the engine so that the block to be removed is vertical. Attach a sling and lift the block slowly. Take care to prevent the rings and pistons from being damaged. Remove the R.H. block first. The illustration (Fig 682) shows one of the blocks being placed on the engine but serves to show the method of removal just as well as it is just the reverse of the assembly when enough mechanics are available to do the work.

One retaining ring for each piston pin should be removed. Use a tool that will not injure the piston material, prying the pin out of the groove by means of the slot milled at the piston pin hole of the piston. Keep each piston pin with its own piston. If the piston pin cannot be removed with the fingers, a tapered wooden plug driven lightly into the pin will accomplish its removal. Remove the L.H. cylinder block in the same manner Remove the pistons from the master rods.

Oil Pan Assembly—The oil pan may be removed after all external oil lines have been removed. The oil pump assembly may be removed either before or after removing the oil pan. The screens should be examined closely for broken cotters and any foreign materials, and then cleaned.

Main Bearing Oil Tube.—The oil tube supplying the main bearings should be removed. Be very careful to avoid springing this tube. Check the diameter of the holes in the flanges. Before re-assembling the engine make sure the holes for the studs are $\frac{9}{32}$-inch diameter. This diameter hole allows for more expansion of the crankcase without putting the oil tube in tension.

Connecting Rod Assemblies—The connecting rod assemblies should be removed next. After the caps are taken off the assembly may be removed through the cylinder hole in the crankcase deck in which the master rod is located. All parts of the connecting rod assembly except the wristpins are numbered.

Main Bearing Caps.—The main bearing caps should be loosened by tapping the keyway side with a rawhide mallet. Remove the caps and take the crankshaft from the engine, taking care not to hit the shaft journals against the studs. The thrust bearing should not be removed unless it is to be replaced by another. Examine the crankshaft very closely for grooves, scratches and loose oil tubes. Remove the crankshaft plugs. Clean the crankshaft assembly thoroughly.

Camshaft Assemblies.—The camshaft and bearings will come off as a unit. Care must be taken to keep the cam followers from being mixed up, in order to reduce the work of re-adjusting the tappet clearance. It is recommended that the bevel gears on the exhaust camshafts be undisturbed unless it becomes necessary to change a gear of the timing.

Valves.—Test the valves with gasoline to see whether or not they need grinding. The valve springs may be depressed with the valve tool furnished in the tool kit. After the locking pin for the cone nut is removed the cone may be unscrewed and the springs taken off. The small spring locking ring must be removed from its groove before the valve can be removed. The valves are numbered just below the threads on the side of the stem and correspond to numbers stamped on the cylinder head next to the valve stem guides. Do not grind the valves unless they need it. The valves should be cleaned, both heads and stems needing this attention.

Overhaul and Assembly.—The overhaul should be carried out on one complete assembly at a time. All parts must be clean before assembling or adjusting. Keep all parts from rusting. Do not use brass or copper locking wire. Use soft iron wire, the largest diameter than can be used. Never use any cotter pins that have been bent, then straightened and bent again. Always use new cotter pins. Keep the engine "closed" as much as possible when working on it. "Closed" means all covers such as gear-case covers in place if they do not interfere with the work. Cover all openings with clean cloth where foreign matter may enter the engine. To do so may save considerable disassembling to remove some part dropped into the engine by accident. Be sure to remove all burrs. Use a rawhide or rubber hammer for rapping parts that would be damaged by a metal hammer.

If possible, during overhaul the engine should be mounted on a rotating stand. The order in which the assemblies are referred to is the order in which the assembly of the engine is carried out at the Curtiss factory. Use new gaskets wherever they are needed.

Top or Partial Overhaul.—If the engine is merely to have a "top" or partial overhaul follow the directions given in the section dealing with a complete overhaul. Do not disassemble more of the engine than is absolutely necessary. Such practices as grinding valves without removing the cylinder block are not recommended.

Complete Overhaul, Crankcase—The crankcase should be washed thoroughly with gasoline, particularly in all corners and pockets in the casting. If a compressed air and gasoline spray is available it provides an excellent means of cleaning. After cleaning, the case should be dried, preferably by an air blast. Examine the casting thoroughly for cracks at all studs, webs and keyways. Examine each bearing shell closely for

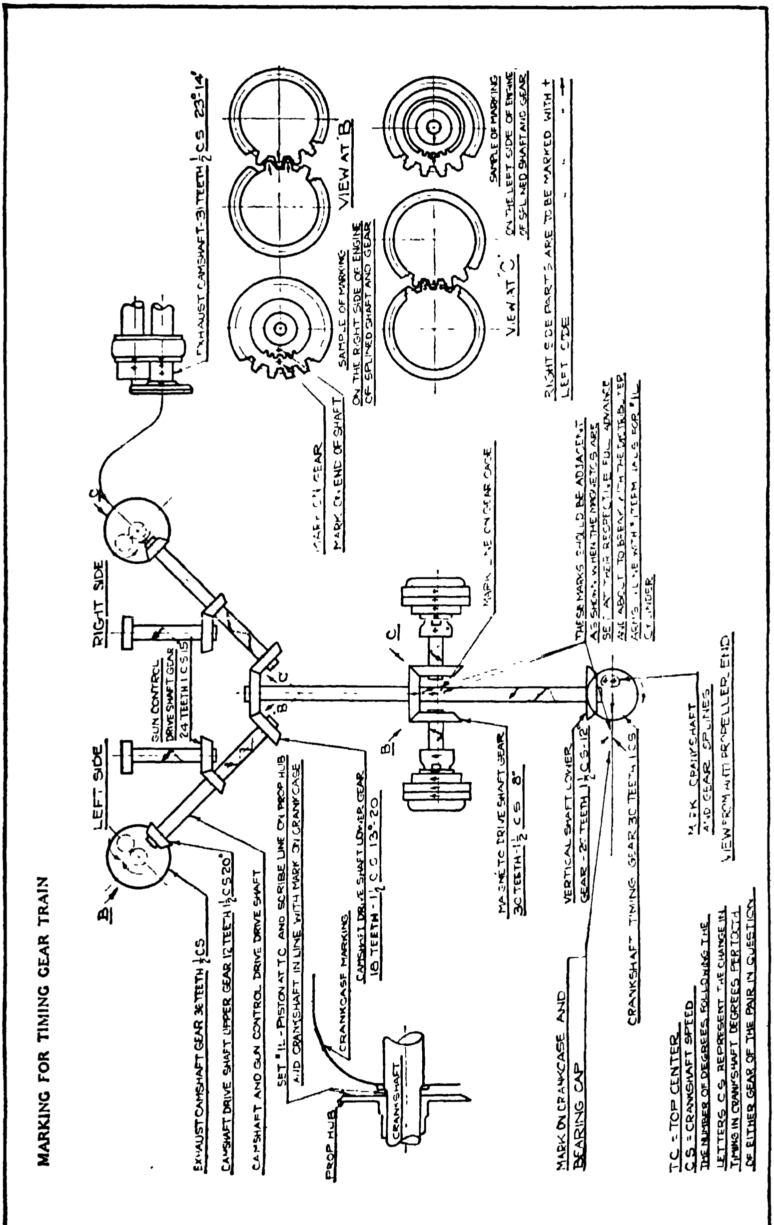


Fig. 681.—Markings for Timing Gear Train of Curtiss D12 Aviation Engines.

loose screws. If any screws are loose tighten them. Do not loosen any tight screws unless the bearing shell is to be removed for replacement. Note the condition of the bearing metal. If the bearings are in good condition do not touch them. Do not scrape or burnish them. Measure them to determine whether they are "out of round" or worn. To measure them assemble each cap on the crankcase. Be sure everything is clean and that the numbers on the bearing caps correspond to the numbers on the crankcase. Draw nuts up to the same tension as if the shaft was in the bearings.

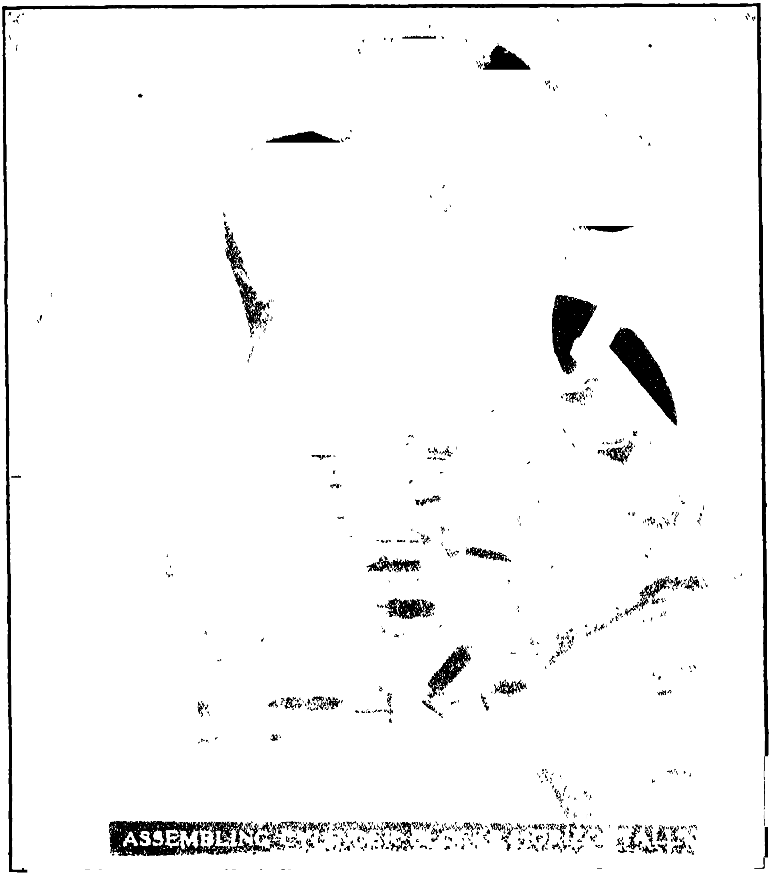


Fig. 682.—Method of Assembling Curtiss D12 Cylinder Blocks Horizontally.

The measurements should be taken by a person who is using the measur- ng tools constantly. Diameters should be taken to the nearest quarter ousandth of an inch and recorded for each bearing. Do not measure cross the joint of the bearing and cap but take the measurements bout one-quarter inch from the joint. Take at least four readings for each

bearing, duplicate readings at right angles to each other. The bearings should be measured with a small inside micrometer or a pair of inside calipers and a micrometer caliper. If the diametrical clearance in any main bearing exceeds .005 inch that bearing should be replaced. Do not replace, scrape or burnish any bearing that does not have to be replaced.

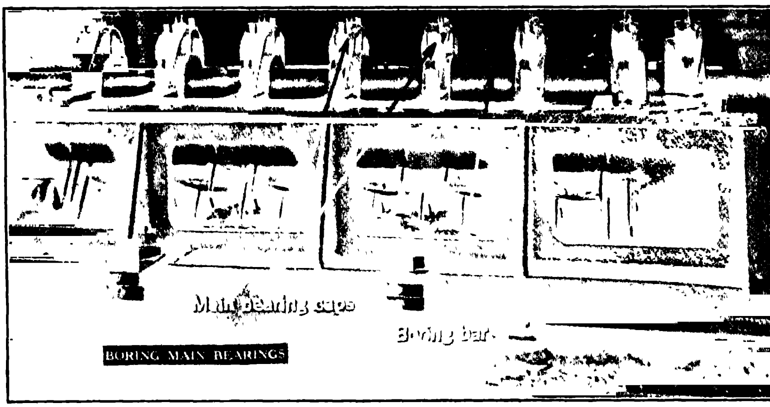


Fig. 683.—Fixture for Supporting Crankcase of Curtiss D12 Engine for Boring Main Bearings.

If any or all the bearing shells are to be replaced, the Curtiss 4,205-T29, fly cutting boring bar assembly should be used for finishing the new bearings to size as shown at Fig. 683. Reaming of bearings is not recommended as this method is too inaccurate. Remove all bearing shells that are to be replaced. Be careful to avoid damaging the slots in the screws. The new shells should be numbered corresponding to the numbers stamped in the crankcase and the caps in the same manner as the old shells were marked. Be sure that the crankcase half of main bearing shell No. 1 has a hole at the top center. If this bearing shell (C-5,145) does not have a hole as described the oil flow to the camshafts will be cut off. A complete set of bearing shells comprises eight C-5,145, six C-5,146, one C-5,151, and one C-5,152 shells. The only difference between C-5,145 and C-5,146 is that there is an oil hole drilled at the center of C-5,145. Each bearing shell and its seat should be well cleaned. Put all the new shells except those for bearing No. 1 and No. 8 in place. The seats and caps for these two bearings are to be used for piloting the C-4,205-T29 tool and should not have the bearing shells in place. The clamp may then be removed.

Each bearing should be fitted so that when the cap is held in place by hand a clearance of .003 inch to .007 inch should exist between the bearing cap and the crankcase web. This gives a clamping fit to insure that the bearing shells are tight against their seats. It is well to have the clearance or "draw" as large as the limits allow. File the ends of the bearing shells until the clearances are right. The assembly should be cleaned and the caps tightened down. All bearings except No. 1 and No. 8 should be cut to size first. Each bearing should be cut with a boring bar assembly a

illustrated. This boring bar and its operating mechanism is placed on the crankcase according to the blueprint (C-4,205-T29) furnished by the makers on request. Use the blueprint. One bearing only is cut to about .0002 inch below the size desired with the cutter and then is burnished to size with the burnishing tool. After boring all except No. 1 and No. 8 remove the boring bar (not its attachments) and put the shells for No. 1 and No. 8 in place. Replace the boring bar and cut No. 1 and No. 8, piloting from No. 2 and No. 7 holes and oil holes. Wash the assembly thoroughly with gasoline. Be sure that the oil passages to the bearings and from No. 1 bearings to the camshafts are clean. Pay particular attention to cleaning the pocket just above the thrust bearing of any accumulation of chips.

Crankshaft Assembly.—Remove the crankshaft oil retaining plugs, wash and dry the crankshaft and replace the crankshaft plugs in their original places. The propeller thrust ball bearing should be first washed with kerosene and dried with compressed air, although the air should not be blown at too high a rate on the ball retainer as it tends to drive dirt between the retainer and the balls. The bearings should then be carefully examined for defects in the outer and inner races, in the balls and retaining cage or retainer. If there are any defects such as pitted bearing surfaces, cracks or rust, the bearing should be rejected. If the visual inspection shows no defects the bearing should be lubricated with a light grade cylinder oil, after which it should be spun by hand to test it for noise. If the bearing runs smooth and approximately as quiet as a new bearing it is satisfactory for use.

The end play in the bearing should be checked taking care that there is no lost motion in the mounting of the dial indicator in order that a thorough reading of the end play can be obtained. It is preferable to mount the indicator on one race checking the motion of the other race. The actual end play should be determined and not the play resulting from twisting the inner race relative to the outer. If the end play exceeds .025 inch the bearing should be rejected. The allowable end play on a new bearing is .010 inch. Inspection of this bearing can be made when it is mounted on the crankshaft.

When assembling a new bearing on the crankshaft heat it to a maximum of approximately 300 degrees Fahrenheit, in hot oil putting it in place on the cold shaft quickly. This method prevents any possible injury to the bearing which might be caused by driving it in place cold. Never drive against the bearing races with a steel drift or hammer.

Measure all journals and crankpins measuring to the nearest quarter thousandth of an inch. Record these measurements along with those of the main bearings for reference to determine the clearances. If there are any oil tubes loose they should be spun in tight with a C-4,215XT-2 tool in an electric drill. Use cylinder oil for lubricant. When ready to assemble the crankshaft in the crankcase all bearings and journals should be well lubricated with oil such as is used in service and the shaft placed in the bearings. Be sure that the oil and bearing surfaces are clean. Do not try to force the shaft into the bearings before assembling the bearing caps. Do not try to turn the shaft before tightening the bearing caps. By plac-

ing the bearing caps in position and tightening them down gradually the shaft will assume its proper position. Be sure the nuts are pulled up tight but do not force them too tight. Cotter pins should fit tight in the holes and should have the ends spread so that the cotter pin is tight enough not to shake. Be sure all slotted or castle nuts are cotter pinned.

Pistons and Piston Rings.—Remove the carbon from each piston head and the piston ring groove, being careful to avoid scratching the piston, especially in the ring groove. To clean out the ring groove use a tool that has the corner rounded to conform to the fillet at the bottom of the groove. The piston should have no rough spots on it, and if any appear stone them smooth with a fine grit oil stone. See that oil holes are clean

The piston rings should be tested for gap clearance. After removing the rings place the piston in the cylinder and place the ring in the cylinder using the piston to line the ring up square with the bore. Measure the gap with a feeler gauge. If the gap is more than .020 inch the ring should be replaced. New rings should have a gap of .007 inch to .009 inch. Piston pins should not be "out of round" more than .001 inch, and should be an easy hand push fit in each respective position after any carbon that may be in the piston pin bearing is removed.

Connecting Rod Assemblies.—If the engine has the old style master rod with the split boss for the 3/8-inch diameter wristpin locking bolt, the locking bolts should be mutilated and scrapped at every overhaul and new locking bolts put in the rods. If the locking bolts are only 5/16 inch diameter, ream out the hole in the boss of the master rod to .3750 + or — .0005 inch for the 3/8 inch diameter (nominal) bolts. Put in new 3/8 inch locking bolts. Clean and examine the connecting rod assemblies. If the appearance of the bearings is good, assemble the bearing caps on the rods and measure the bearings. Record the measurements and compare with the crankpin dimensions. The average diametrical clearance should not be greater than .0045 inches. If necessary to replace any bearing shells the old shells may be removed by cutting off the outside end of the brass rivets. Remove the rivets and the shells can then be removed. New shells should be clamped in the rod by means of a C-9,225-T1 clamp or similar tool and rivet holes bored with a No. 11 (wire gauge) drill. The X2,487-F1 tool is used to countersink each hole 1/16 inch below the rough babbitt surface for the head of the rivet. If a riveting fixture (C-1,252 T-10) is not at hand the clamp should be left on and the brass rivets set solidly. The shell is assembled in the cap by the same method.

The clearance or "draw" between the master rod and its cap should be .003 inch to .006 inch. To fit to this clearance the cap should be held by hand on the master rod. Be sure the cap is in its proper position, that is, the bolt holes should be in line and the cap in its marked relation to the rod. Determine the clearance with a "feeler" gauge. The surfaces of the bearing shells that are in contact should be straight and square. Test this surface with prussian blue or a similar compound. The bearing cap must not rock. If the bearing has the same clearance at the four bolt holes and the clearance is greater at the center it will fit properly, but if the clearance at the center is less than that at the bolt holes the bearing cap will be strained. To obtain the correct clearance a "second cut" file 3/8 inch to 1/2 inch wide

is recommended for filing the ends of the bearing shells. Do not file all the metal that is to be removed. Finish the last .0005 inch or .001 inch by rubbing the cap on a sheet of fine emery cloth which is supported by a surface plate. This will give a good surface to the ends of the bearing shell. Wash the parts thoroughly.

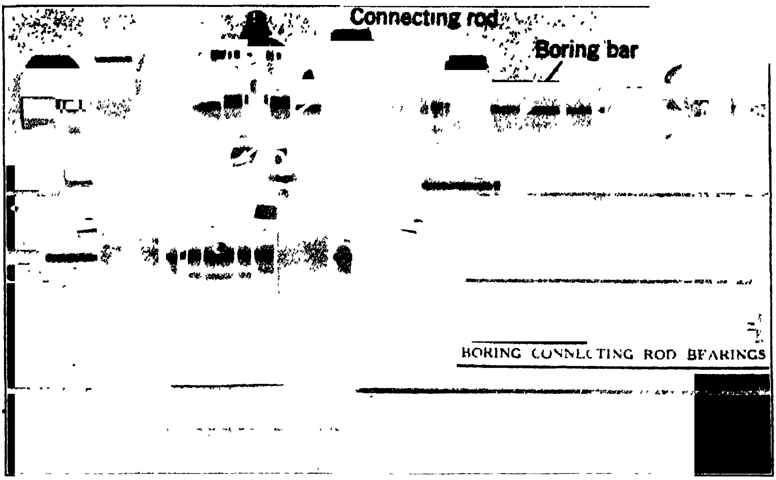


Fig. 684.—Fixture for Boring Connecting Rod Bearings of Curtiss D12 Engine.

This "draw" causes the bearing shells to fit very tight in the rod when the cap is assembled. Assemble the rod for boring the bearing. Each bearing should be bored out in a jig or fixture similar to C-1,252T-4 shown at Fig. 684 to .002 inch to .0025 inch of the crankpin. A flycutter should be used to cut the bearing to a diameter about .0002 inch less than the finished diameter. The bearings should then be burnished to the desired size. Reaming the bearings is Not Recommended.

The piston pins should be an easy push fit in the piston pin bushings. If necessary to renew the bushings the old ones should be pressed out and new ones pressed in. The two oil holes should be drilled with a $\frac{5}{16}$ inch drill. Remove the burr. The bushings should be ground out in a fixture similar to C-1,252-T1 at Fig. 685 to give a clearance of .0005 inch to .0020 inch on the piston pin.

The wristpins at the lower end of the articulated rod should be examined for loose oil tubes and for wear. If the wristpin clearance exceeds .004 inch, the bushings should be replaced. The normal clearance is .0000 inch to .0015 inch. If it is necessary to fit new wristpin bushings the old one should be removed as follows:—Form a spacer to fit snug between the forked ends. This spacer is easily made from a piece of $1\frac{3}{8}$ inch I.D. by about .085 inch steel tubing. Cut the tubing off square just a trifle over $\frac{3}{16}$ inch in length and dress it down square until it just fits into the forked end, between the steel ends. Cut about one-third the ring of tubing out and use it as shown in Fig. 686 A as a spacer to prevent springing

the rod while pushing the bushings out.

When a new bushing is about ⅛ inch from seating, a small scraper should be used to remove the burr under the shoulder. After thoroughly cleaning out under the shoulder, the bushing should be pressed in the remainder of the distance as shown at Fig. 686 B. These bushings should be ground to give the correct clearance on the wristpin (.0000 inch to .0015 inch). A fixture similar to that shown at Fig. 684 should be used to make sure that the wrist and piston pin holes are at right angles with the center line of the rod, using mandrels of the proper size at upper and

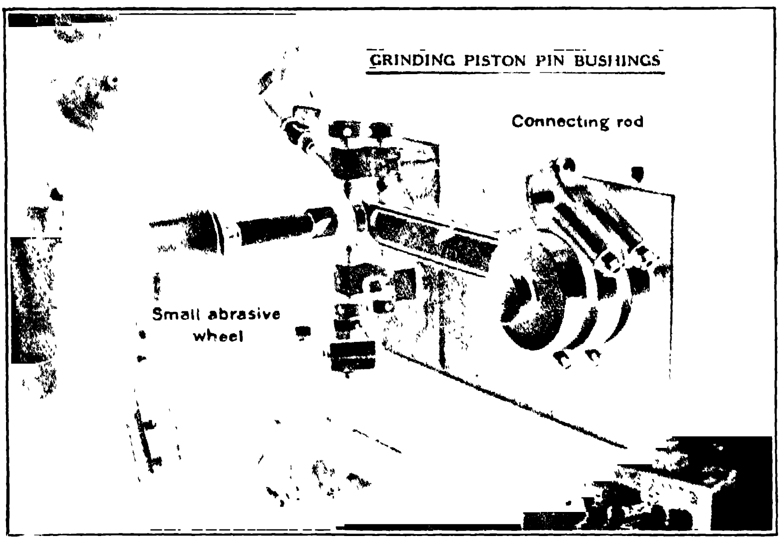


Fig. 685.—Jig for Supporting Curtiss D12 Master Rod when Grinding Piston Pin Bushing.

lower bearings. When all parts are correct the rods should be assembled. The bearings should be free enough so that the short rod will fall easily by its own weight. All corresponding parts except the wristpins and bolts are numbered. The locking bolts for the wristpins should be tight and the nuts cottered. The bolt goes in the rod with the nut down.

Oil the connecting rod bearings and the crankpins. Assemble the connecting rod assemblies on the crankshaft. The short rod should be put through the hole in the deck (top of crankcase) first, with the master rod following. Then the short rod can be moved under the crankshaft and placed in the opposite deck hole, (Fig. 687). Be careful to avoid scratching the crankpins. Bring the bearing up to the crankpin and put the cap over the bolts. Put on the nuts and draw the bearing together gradually and evenly. When ready to run the master rod should be on the left hand side of the engine. Be sure all nuts are cotter pinned. See that the cotter pins cannot move. Assemble the main oil tube on the main bearing cap. Do not force it. Use new gaskets if necessary. Cotter pin all nuts and bend the pins so that they cannot move.

Oil Pump Assembly.—The oil pump assembly should be taken apart and cleaned thoroughly with gasoline. First, remove the pressure pump cover. There is a small locking ring on the end of the pump shaft and the gear cannot be removed until the lock ring is taken off. Be very careful not to lose this lock ring. The idler shaft may be lifted out and the idler and drive gears removed. After the drive gear is removed a slot may be seen where the pump shaft passes through the housing. Do not try to drive the pump assembly apart. Turn the pump shaft until the key lines

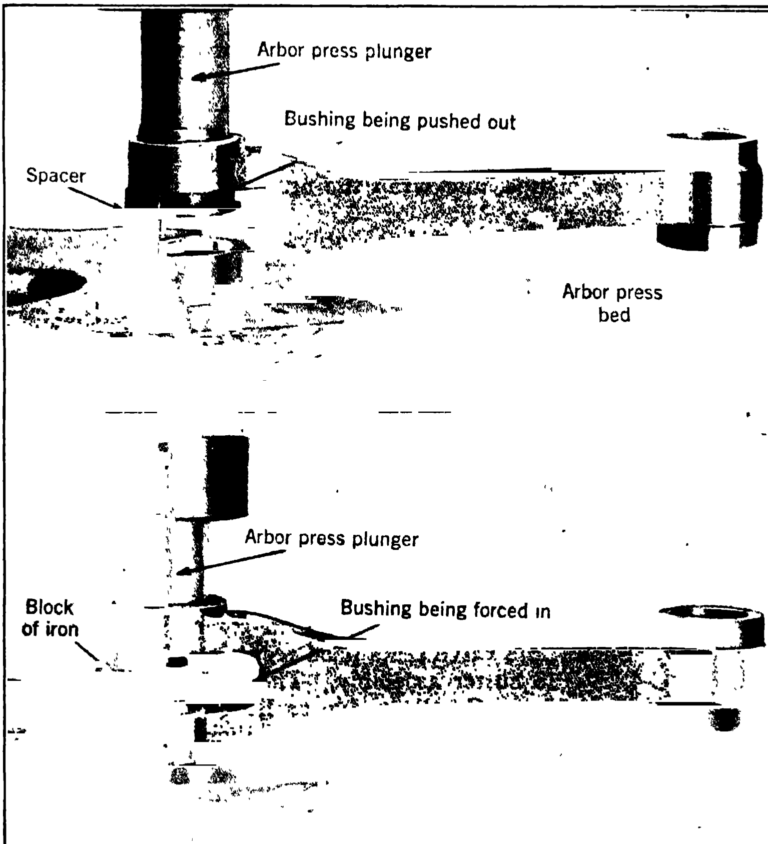


Fig. 686.—Method of Removing and Assembling Wristpin Bushing from Lower or Yoke End of Link Rod of Curtiss D12 Engine.

p with the slot. Then the pressure pump housing may be slipped off ver the pump shaft. The other gears and housings may be removed in similar manner. Do not remove the main drive gear from the pump shaft nless a new one is to be assembled. See that the cotter pin is tight. Oil pump parts show very little wear as a rule.

Inspect all parts as they are removed and clean them thoroughly. If no arts need replacing (due to wear or interference) the pumps may be

re-assembled. All gears and housings will fit together only one way. The housings are correctly located by dowel pins. Do not use any oil when assembling the oil pumps. Put the bolts through the top housing with the heads at the pump drive gear end. Put the driveshaft through the screen and the top housing and assemble the gears so that the numbers on the housings and the gears correspond. Put the idler shaft in place and slip on the center housing and assemble its gears.

The pressure pump should be assembled next. Do not forget to put the lock ring on the driveshaft. Put the pressure pump cover on and assemble the nuts on the bolts. Draw all nuts up snug and turn the shaft with the fingers. It should turn easily. If the shaft cannot be spun the housings may be shifted slightly by holding the pump assembly in one hand and tapping the various housings with a rawhide hammer until everything is free. Then tighten up the nuts and cotter pin them. After determining that the pump runs freely by making the above adjustments, oil the pressure and scavenger pumps, and wrap the assembly in paper or cloth so that no dirt can enter.

The oil pan should be cleaned thoroughly. Be sure the studs and nuts (or screws) in the oil pump idler gear are securely locked. If the engine is one of the earlier D12's it is recommended that the new stud assembly be put in place of the cap screws of the idler gear. Assemble the oil pump assembly on the oil pan. This assembly will fit only one way due to one stud being unequally spaced with the others. The oil pan may now be assembled on the crankcase. Put on the oil tube from the pressure pump to the crankcase. Turn the engine right side up as it is now ready for the cylinder assemblies. If the cylinder blocks are not ready be sure to cover the assembled case so that no dirt can enter through the holes in the decks.

Cylinder Blocks.—The cylinder blocks should have the carbon removed and should be washed. Look at the cylinders to see if any of them are scored or otherwise marred. If any cylinders are rough they should be lapped smooth. If necessary to grind the valves, Clover Compound grade A is recommended for use. Be sure all compound is washed out after grinding. Should the valve seats need recutting the work should be done with a C-4,159-T13 cutter assembly. The valves should be ground to an angle of 45 degrees. Cut the valve as little as possible. Use the tool furnished in the tool kit for grinding the valves. The valves should be gasoline tight in three positions after being ground. After cleaning, assemble the valves and valve springs. A special valve spring depressing tool as shown at Fig. 688 will facilitate the process. Assemble the lock rings on the valve stems. The split cone nut should be screwed on the stem until the top edge of the valve spring washer is $1\frac{3}{16}$ inches from the top machined surface of the cylinder head. If any of the cam followers have the split ends or the locking screws bent replace with ones that are in good condition. Assemble the cam followers in their proper positions.

Oil the cylinder walls with clean engine oil immediately after cleaning. Be sure that both lock rings for each piston are in their respective grooves using the double tubular tool provided in the tool kit. The double tubular tool is used as follows for inserting the piston pin locking rings in the pistons. Slip the ring into the larger sleeve and then put the smaller sleeve

into the larger opposite the bevelled end. Place the bevelled end of the larger in the piston pin hole and give the inner sleeve a sharp rap, driving it into the piston pin hole with the lock ring ahead of it. The lock ring will snap into place in its groove.

If a number of mechanics are available the cylinder blocks are easily assembled by setting the crankcase so that the cylinders may be held horizontal and slipped on over the pistons, (Fig. 682). Oil the pistons and clamp the piston rings of pistons 3L and 4L with the brass clamps (C-4,285). Turn the crankshaft until the above pistons are nearly at the top of the stroke. Now the cylinders may be slipped over pistons 3L and 4L until the piston rings are all in the cylinders. Then remove the C-4,285 clamps and use them for clamping the rings of pistons 2L and 5L. If these pistons do not take a position far enough beyond 1L and 6L to allow the rings to enter before the latter pistons are ready to enter their respective cylinders the crankshaft should be turned slightly to remedy this condition. The cylinders should be slipped over pistons 2L and 5L until the rings are in the cylinders at this point. Clamp the rings on 1L and 6L and push the cylinders on. Remove the clamps and slip the cylinder block down over the studs. Put at least four nuts with lock and flat washers on the studs so that the cylinder assembly cannot move.

If but two mechanics are available the cylinder blocks should be assembled by using chain falls. Do not assemble the pistons on the short rods until the L.H. block is assembled on the engine. The chain falls should be used to hold the cylinders in place rather than to lower them. Turn the crankcase so that the L.H. deck is horizontal. Turn the crankshaft until pistons 3L and 4L are about three-fourths the way up. Lower the cylinder blocks until the ends of the sleeve nearly touch the pistons. One mechanic should guide the pistons while the other turns the crankshaft. This will push pistons 3L and 4L into the sleeves until the rings are in the cylinders. Similarly, lower the cylinder block over the other pistons and turn the engine upright. The pistons should be assembled on the short rods and the R.H. block put on the engine. Be sure the lock rings are all in the pistons.

It is recommended that the following procedure be carried out in tightening the cylinder hold-down nuts. Tighten the nuts on the end studs (long ones) in the Vee and then tighten the corresponding nuts on the outside of the block. This will draw the cylinder block down evenly. Turn the engine so that the same procedure can be carried out with the R.H. block. Tighten all cylinder hold-down nuts evenly.

Put the intake sparkplugs in tight. Put on the oil tube that supplies the camshaft bearings and lock the cap screws with locking wire (.042 inch diameter soft iron wire No. 19 B. W. Ga.). Cover the intake "L" manifolds so that no dirt or foreign matter can enter the engine.

Carburetion Assembly.—The carburetion assembly should not be completely disassembled unless the carburetors have been causing faulty operation. A bench check is sufficient if the carburetors have been functioning correctly. This should be carried out as described in the chapter dealing with Stromberg carburetors. To re-assemble the carburetors assemble the "Y" pipes and other equipment to complete the carburetion assembly as it

was when removed from the engine. Leave the screws or nuts fastening the "Y" pipes to the carburetors loose. Uncover the intake "L" manifolds. Be sure the manifolds are clean, then fasten the carburetion assembly in place. Be careful to avoid springing any parts. Cover all openings where dirt can enter. Tighten the cap screw or nuts holding the carburetors to the "Y" pipes.

Gearcase Assembly.—Remove the water pump and take off the pump cover. If there is no clearance between the cover and the impeller the parts will show evidence of rubbing. The clearance should be not less than .015 inch. See that the impeller is tight on its shaft. The shaft should have .003 inch to .006 inch end play in the housing. To remove the pump shaft it is necessary to remove the taper pin holding the dural collar just above the ball bearing. Be sure to note which way the collar was assembled. There is a center punch mark on the shaft and another on the dural collar. The mark on the collar is above the hole for the taper pin and is just below the mark on the shaft. Remove the screw holding the packing gland nut locking device. Take off the locking device and back off the gland nuts to relieve the packing pressure from the shaft.

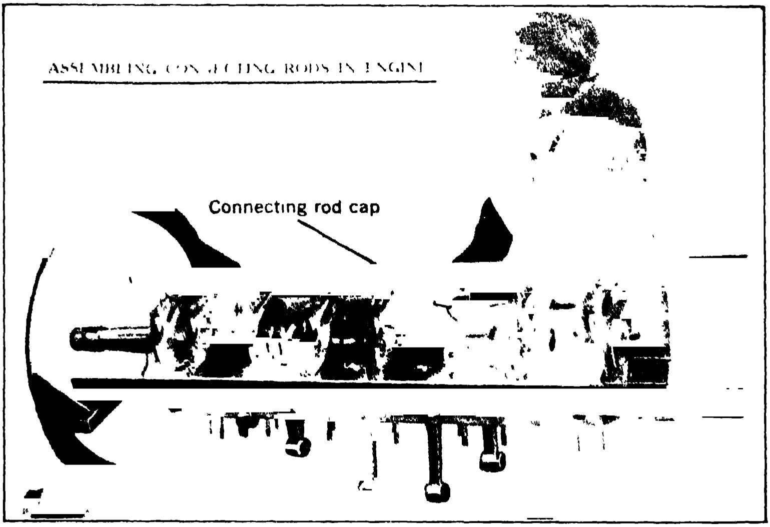


Fig. 687.—Assembling Connecting Rods to Crankshaft of Curtiss D12 Aviation Engine

The shaft and impeller should be removed as a unit. Do not try to remove the impeller from its shaft. The shaft and impeller may be driven out by tapping the shaft lightly with a rawhide hammer, holding the housing in one hand. Clean and inspect all parts and if there are no replacements needed re-assemble them. Put the shaft in place. If the packing glands need more packing simply add what is needed. Do not remove the old packing. Lubricate it with cylinder oil before adding the new packing. The new packing should be well oiled before being placed in the glands. Crandal Packing Company's Style No. 142 is recommended.

If there is not enough room for more than a few strands of the packing add only those strands.

Assemble and pack the housing for the ball bearing. Put the bearing in place and pin the collar to the shaft. Bend the cotter pin so that it cannot "shake." Assemble the gland nut locking device. See that no parts interfere and assemble the cover. Lock the screws with wire. Each camshaft driveshaft housing, camshaft driveshaft and its gears, and the gun control drive may be removed as a unit from the gearcase casting. Remove the covers from the gearcase. Check the end play of the upper and lower vertical shafts before removing the taper pins. The end play of the upper vertical shaft is set between .007 inch and .010 inch when the engine is built. That of the lower shaft is set between .006 inch and .014 inch. If the adjustment of the gears is not seriously altered by their being more than the specified end play there is no need of replacing the bushings. (The proper adjustment of the gears is treated separately.) A diametrical clearance greater than .006 inch is sufficient cause for replacing the bushings.

The nut on the end of each shaft has a small file mark to denote which way the nut should go on the shaft. The vertical shafts are removed by removing the taper pins and unscrewing the plain nuts. There is no need of removing the upper gear or the ball bearing of the upper vertical shaft unless the gears are to be readjusted Be careful to keep the gear, shim, pin and nut with its proper shaft. This will facilitate re-assembly. Clean and inspect all parts.

If it becomes necessary to replace a bushing for either of the vertical shafts the locking pin in the gearcase must be drilled out and the bushing driven out. A new bushing (C-4,094) should be driven in by means of a mandrel and pinned in place. The bushing may be reamed to size piloting from the other bushings. While reaming, the gearcase should be fastened to a surface plate, with the starter deck up. The bushing should be faced off with a C-6,029-T1 tool until the proper end play for the shaft is obtained. The shaft must be assembled using the same shims and gears before adjusting the end play. There is no need of readjusting the gears unless a new gear is to be fitted or excessive backlash exists, (.025 inch) being considered too much. Unless the gears are to be readjusted or replaced they should not be removed from the camshaft driveshafts. If the gun control drive assembly is removed all gears and bearings may be inspected without further disassembling.

The magneto coupling assemblies should be removed. Unless there is radial play or a great amount of end play in the ball bearings there is no necessity for taking the assembly apart as the condition of the assembly can be determined by feeling for lost motion. If the gear needs replacement the assembly must be taken apart. Grip the gear in a vise with soft jaws and remove the nut and lock washer from the upper end. Then remove the housing from the gear. One ball bearing is held in the housing and the other is on the gearshaft. Between the bearings are one or two shims.

If the bearing must be removed from the housing the retaining ring must be removed first. Use a tool with a rounded point. Push one end of the ring from its groove by inserting the tool in the hole provided and

forcing the ring out. The ring may then be removed by gripping the end with a pair of pliers and turning the ring so as to make its diameter smaller. Do not forget to replace the ring when assembling. To re-assemble the magneto coupling assemblies, place the lower bearing on the gearshaft Then put the shims in place and assemble the housing and its bearing over the shaft. Oil the bearings with cylinder oil. The splined coupling goes on next. Be sure the etched marks line up. Then place three shims of .003 inch material at equal distances around the coupling between it and the aluminum housing. Put on the washers and the nut and tighten. Remove the .003 inch shims and try the assembly. See that it rotates freely and smoothly.

The gun control drives should have no radial play in the bearings. There should be not less than .005 inch clearance between the top of the housing and the flange on the gun control shaft. The end play (in the housing) of the gun control shaft and bearings should not be greater than .004 inch or less than .001 inch. The shaft should rotate smoothly and easily. See that the cotter pin is tight. Should it become necessary to take the gun control drive apart remove the taper pin and unscrew the nut. Hold the upper end of the shaft in a vise with soft jaws while removing the nut. Remove the gear, ball bearing and shims. Do not remove the ball bearing from the housing except for replacement. To remove the bearing from the housing the retaining ring must be removed before bearing can be taken out. Remove the ring as described in the section concerning the disassembly of the magneto coupling assemblies. Keep the parts of each gun control drive together and do not get them mixed with any other. Keep all parts clean.

A new bearing in the housing should have end play in the housing of not less than .001 inch nor more than .004 inch. Be sure to put the retaining ring back in place. It is recommended that one end of the ring should be not more than one-half an inch from the hole in the housing. Assemble the parts on the gun control shaft as they were before removal. Oil the bearings. The shims should be between the bearings. Mesh the marked splines. Tighten the nuts and drive in the taper pin if it is in good condition. If it is not, fit a new one. See that the cotter pin is tight enough so that it cannot "shake." Keep all assembled units clean. Cover them up so no dust or dirt can enter.

The camshaft driveshaft is located by the housing that contains the ball bearing. Do not remove the upper gear unless a new one is to be substituted or a readjustment made between it and the camshaft bevel gear. Its condition and that of the bearing can be determined without removing them from the shaft. Remove the taper pin and take the nut off the lower end of the shaft. The gear can then be taken off the spline There is a shim between the gear and the bearing. Keep this shim with the gear. The housing containing the bearings may be removed after loosening the packing gland. There is another shim between the bearing and a shoulder on the shaft. This shim controls the adjustment of the gun control drive gears. Mark it and keep it with its proper shaft. The shaft can now be taken out of the housing.

The lower ball bearing should not be removed from its housing except for replacement. The retaining ring is similar to that of the magnet

coupling drive housing and should be removed and replaced similarly. There should be not less than .001 inch and not more than .010 inch end play of the bearings in the housing. To re-assemble, place the shaft in the housing. Put the correct shim on the shoulder of the shaft and slip the bearing housing over the shaft. Oil the bearing and place the gear and its shim in place. Be sure the marked splines mesh. Tighten the nut and put in the taper pin. Do not use any taper pins that seem liable to break at the cotter pin hole. See that the cotter pin is tight. Assemble the upper vertical shaft in the gearcase, using the shim that was taken out unless a new gear or shaft is to be used. Oil the shaft and bushings.

Put the 151-D shim and the lower gear on, making sure the marked splines mesh, and tighten the nut. Line up the hole for the taper pin. Assemble the lower vertical shaft (pump driveshaft) the same way. On all models before the D12D the cover for the top of the gearcase should be put on to align the upper end of the shaft. On D12D engines and subsequent models the steel liner should be placed in the upper opening of the gearcase. To try the gears place the crankshaft gear in place. See that the marked splines are meshed. Mark the timing marks with a colored pencil.

Put the gearcase on the engine. Make sure that the timing marks of the crankshaft gear and the lower gear of the upper shaft line up according to Fig. 681. The gears should be clean and dry for testing and all oil should be washed off them. Fasten the gearcase to the engine by enough screws and nuts to hold it in its correct position.

Turn the crankshaft a little at a time, and at each new position of the crankshaft lift on the upper shaft and try the backlash of the gears. This can be done easiest by placing two fingers at opposite sides of the lower gear of the shaft. The finger tips should rest on the gear teeth. Push the gear up against the bushing and rotate it back and forth. The magnitude of the backlash can be estimated by an experienced mechanic, or preferably by means of narrow feelers or a dial indicator. Test the backlash of the upper gear of the lower vertical shaft the same way. Hold the gear down against the bushing. Try the gears through two full turns of the crankshaft. Note how the back angles of the two gears line up. They should line up within $\frac{1}{64}$ inch. Both the upper and lower shafts should start to rotate at the same time.

If these gears fit satisfactorily assemble the magneto coupling assemblies on the gearcase. Do not forget to have the timing marks lined up before assembling the magneto couplings to the gearcase. Mesh the marked teeth. Tighten the gearcase attaching cap screws. Hold the vertical shaft lower gear up against the flange of the lower bronze bushing and rotate each magneto coupling back and forth. Turn the crankshaft slightly and try the coupling gears again. If both couplings are tested at the same time one complete turn of the vertical shaft will determine whether or not the backlash is satisfactory.

The fit of the gears may be changed if necessary by changing the 151-D shim under the lower gear of the vertical shaft and changing the shims in the magneto coupling drives.

The backlash is set at .003 inch to .010 inch at the factory but as much as .020 inch may be allowed. If the gears wear at a faster rate they should

be readjusted to have the backlash as originally specified. (.003 inch to .010 inch.)

If the backlash is satisfactory and the back angles of the gears line up within $\frac{1}{64}$ inch, the screws that hold the coupling assemblies to the gearcase should be locked with a soft iron locking wire. (.042 inch diameter No. 19 B.W.G.)

Turn the crankshaft so that all the timing marks line up according to Fig. 681. Assemble the camshaft driveshafts and their housings on the gearcase. Use the gaskets where they belong. Be sure the marked teeth mesh. Fasten the upper end of each housing to the cylinder block. Check the backlash of the lower gears of the camshaft driveshaft and the upper gear of the vertical shaft. The backlash and the back angles should be as specified for the other gears. These gears are adjusted by changing the shims under the gears of the vertical shaft and the camshaft driveshafts.

For purposes of illustration suppose the gear on the left hand camshaft driveshaft has too much backlash, and the back angles of that gear and the upper gear of the vertical shaft do not line up within $\frac{1}{64}$ inch with the gear of the vertical shaft too high. If there were only these two gears to be considered the backlash and back angles could be made satisfactory by merely placing a thinner shim under the gear of the vertical shaft. However, suppose the fit between the gear of the right hand camshaft driveshaft and the gear of the vertical shaft is satisfactory, then lowering the center gear (on vertical shaft) will correct the fit between it and the left gear but will spoil the fit between the others. This is an extreme case and the only remedy is to lower the center gear a little and raise the right hand gear a little. It will probably make the fit a trifle loose and the back angles slightly off on both sides but this compromise will give satisfactory operation.

If the back angles of the center gear are high and both right and left gears are loose, merely lowering the center gear will usually correct the backlash and back angle at the same time. If both side gears are tight and their back angles drop below that of the center gear the fit may be made satisfactory by placing a thinner shim under each side gear. Be sure that the vertical shaft is held up against the flange of the bronze bushing when testing the backlash and back angle of all gears. This is the position in which the shaft runs due to the thrust of the gears.

Remove the plug from the camshaft driveshaft housing at the gun control drive. Put the gun control drive in its proper place and tighten it down. Use the gasket. Test these gears as the others were tested. The back angle may be viewed through the hole in the housing. These gears are adjusted by moving the large one up or down by changing the shims in the gun control drive and by moving the camshaft driveshaft up or down, by changing the shim between the lower ball bearing and the shoulder on the shaft. Changing the latter does not alter the fit between the lower gear and the gear on the vertical shaft, provided the shim between the lower gear and the bearing is not changed. It does alter the relation between the hole for the taper pin and the castellation of the nut.

As soon as the gears treated to this point are fitted satisfactorily the shafts may be "pinned up." If the holes for the taper pins do not line up

on account of changing shims, or the pins do not line up with the castellation, they may be made to, by filing the "clamping" side of the nut. Be sure the filed surface is flat and at right angles to the longitudinal axis of the thread. This will avoid a cramping action. Oil all bearings. Tighten the nuts. Put the taper pins in and cotter them so that the cotter pins cannot "shake." Be sure all parts are clean. Be sure that the etched splines are meshed and that the timing marks agree with Fig. 681.

It is advisable to remove the gearcase from the engine for assembling. After the parts are assembled lay the gearcase down so that oil may be put in the hole leading to the bushings for the upper vertical shaft. Put as much oil as possible in this recess. Assemble the gearcase on the engine, but do not lock the cap screws. Be sure that the timing marks agree with Fig. 681. Use the same gaskets that were used while making adjustments. Usually there will be no need of making adjustments in the gearcase and the fits need only to be checked before putting the taper pins through the nuts and shafts. Wash the camshaft assemblies.

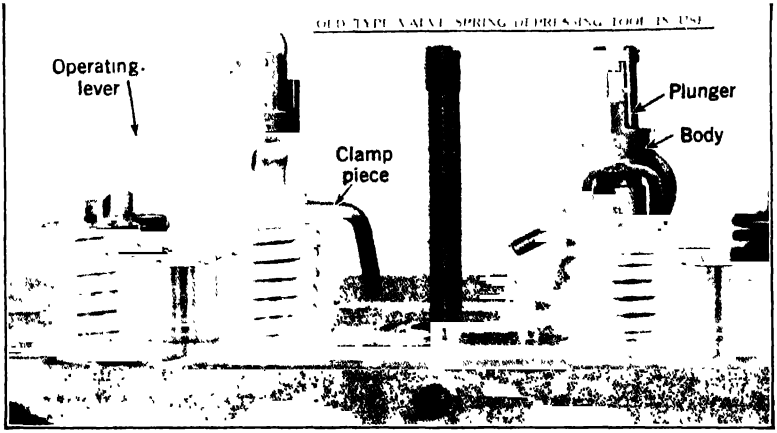


Fig. 688.—Side and Front Views of Old Type Valve Spring Depressing Tool in Use on Curtiss D12 Motor. Plunger Clamps Valve Stem, Body Pushes Down Against Valve Spring Retention Collar.

All engines after No. 445 and those overhauled at the Curtiss plant since February 15, 1927, have the following marks in addition to the prick-punch mark on the gears of the camshaft:—The rear rib of No. 1 camshaft bearing has two arrows stamped on the top. When the engine is timed correctly and in firing position on cylinder No. 1L, these arrows and the etched arrows on the camshaft flanges should be in line.

Remove the center nuts, take the camshaft bearing caps off and remove the camshafts. The camshaft bearings should be wiped out and inspected. Examine all camshaft bearings thoroughly for cracks. Recondition or replace any bearings that are not in first class condition, and wash up the camshaft and replace in the bearings. Use plenty of oil. Check the mesh of the marked teeth by comparing the marks on the flanges and the bearing caps. Assemble the camshaft bearing caps. Put on the small nuts

and washers. Assemble the shafts and bearings on the head, drawing the nuts down evenly. Use oil on the threads to prevent seizing the nuts. If the bearings are not drawn down evenly the dowel pins may not enter the holes in the bearing "feet" and further tightening of the nuts is liable to crack the bearing. Be sure to cotter pin all nuts. Tighten the cotters so that they cannot "shake." The timing marks on the bevel gears must mesh according to the diagram.

The tappets should be adjusted (with the cams in an upright position) to give a clearance of .014 inch to .016 inch and the valves should be synchronized, that is, both should open and close at the same time. To set the clearances, the lock screws should be loosened and the screws that fit over the ends of the valve stems adjusted until the desired clearance is obtained. The synchronization can be obtained by putting a finger tip between each valve spring retaining washer and the cam follower and forcing the cam follower down slightly, by prying with a thin bladed screwdriver between the cam follower and the camshaft. There should be no lost motion between the valve washer and the cam followers when properly synchronized. Both valves must open at the same time. When the clearance is correct and the valves are synchronized tighten the locking screws and recheck the clearance and synchronization. If the bevel gears were removed put each bevel gear back on its own camshaft using the same shim that was taken off. Make sure that the timing marks are in alignment

Check the backlash between the bevel gears. Use the bronze hook wrench. Hold the small gear and turn the large one back and forth for each position of the crankshaft to determine the backlash. Be sure the gears are tested through one full revolution of each camshaft. The alignment of the back angle can be easily seen. If it becomes necessary to change the adjustment of the bevel gears the easiest way to adjust them is to take the nut off the upper end of the camshaft driveshaft, then loosen the gearcase enough so that the gear can be taken off. Put a thicker shim under the gear if there is too much backlash or a thinner one if there is too little. Replace the gearcase and tighten the nut on the upper end of the camshaft driveshaft. Try the gears. If the backlash and back angle are satisfactory, replace the taper pin. See that the cotter pin is tight. Be sure the timing marks line up correctly.

Checking D12 Timing.—The engine will be timed correctly if the timing marks line up according to Fig. 681, but the timing should be checked. First, it is necessary to find the top dead center of piston 1L (one left) by "tramming." This can be done by using a device similar to that shown in Fig. 689 A or some similar device. A timing dial should be fastened to the propeller shaft. Set the pointer to any one position and turn the shaft until the lamp indicates that the circuit is closed. Note the reading of the dial. Turn the engine slowly in the same direction (direction of rotation) until the light goes out. Note the reading on the dial. The top dead center is half way between these two readings. Turn the engine in the direction of rotation to half way between the two readings. Then shift the pointer to read zero on the dial. Check as before and see that the lamp light the same number of degrees before top center as it goes out after top center. Turn the crankshaft until the timing marks line up. These marks

should line up, or agree with Fig. 681 when the piston is 32 degrees before top center. There is only one stroke in which all the timing marks line up.

Turn each magneto shaft so that the marks on the distributor gear and its housing line up. Then put the magneto on the engine. Be sure the marked ends of the couplings line up. The stamped arrows should line up with the line scribed on the gearcase and the marks on the distributor gears and housing should line up.

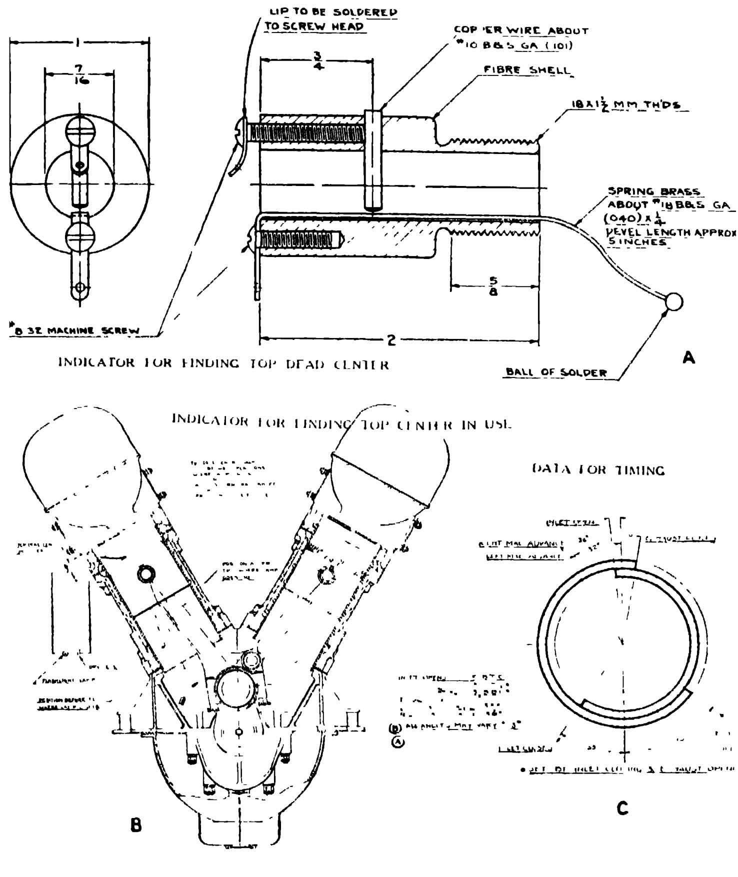
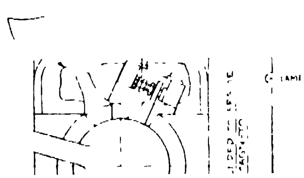


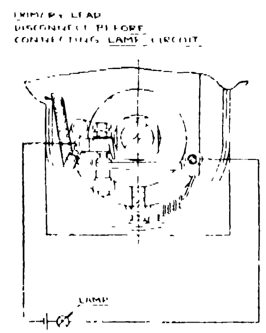
Fig. 689.—Indicator for Finding Top Dead Center of Curtiss D12 Engine Shown at A. B—Method of Using Lamp and Dry Cell in Circuit with Indicator. C—Data for Timing D12 Engine.

Check the magneto timing in the following manner. For Scintilla AG-12D magnetos. Remove breaker assembly from the left hand magneto and put a thin piece of fiber or other nonconducting material over the contact back of the upper part of the breaker assembly. (Fig. 690 A.) Put the assembly back in place and connect a flashlight lamp and dry cell in

series with the breaker points, that is, ground one wire and connect the other to the fixed breaker point. Turn the crankshaft backward to about 40 degrees before top center. Turn the shaft in the direction of rotation just enough to make the lamp go out. This should occur at 32 degrees B.T.C. full advance. If it is necessary to change the magneto timing it can be done by removing the two bolts from the rim of the couplings and rotating the aluminum and steel parts with respect to each other. Put the bolts back in the two opposite holes that they will go in and tighten them up. Check the timing. If it is correct put cotter pins in the bolts. The R.H. magneto should fire four degrees before the L.H. magneto. Remove the fiber strips from the breaker assembly.



WIRING DIAGRAM FOR CHECKING IGNITION TIMING OF SCINTILLA AG 12-D MAGNETO



WIRING DIAGRAM FOR CHECKING IGNITION TIMING OF SPLITDORF SS-12 MAGNETO

CONNECTIONS FOR TIMING MAGNETOS

Fig. 690.—Connections for Timing Magnetos on D12 Engine.

Turn the crankshaft in the direction of rotation until piston 1L is on T.D.C. Note the position of the cams for cylinder 1L. They should both point toward the other block of cylinders and their upper surfaces should be nearly parallel and almost parallel to the cylinder head. This serves as a check to determine whether or not the magneto fires during the correct stroke. For Splitdorf SS12 magnetos. Remove the primary lead (flexible wire in breaker assembly housing) and connect the breaker points in series with a flashlight lamp and a dry cell, (Fig. 690 B). Check the timing as described for Scintilla magnetos. When the timing is correct reconnect the primary lead.

To check the valve timing the following procedure is recommended. Turn the crankshaft until all the timing marks line up. Then continue to turn in the direction of rotation until the exhaust valves for cylinder 1L are nearly ready to open. If there is only one mechanic, hold the valve spring retaining washer of one valve with the fingers of the right hand exerting a rotative force on the washer. Use a long bar (about four feet) in the left hand and rotate the shaft slowly just before the valve opens. If there are two mechanics one should turn the shaft and the other should determine when the valves open. Record the dial reading, for

instance 52½ degrees B.B.C. (before bottom center). The reading should be within three degrees of that stamped on the name plate. Usually the reading is about 52½ degrees B.B.C.

Turn the crankshaft in the direction of normal engine rotation until the intake valve is nearly ready to open. Determine its opening point as for the exhaust valve and record the reading (five degrees B.T.C., etc.). Next determine the closing point of the exhaust valve. To determine this rotate the valve spring retaining washer with the fingers and when the valve closes, the mechanic can feel the valve "grab" the seat and stop turning. Record the actual dial readings. Find out when the inlet valve closes. This completes the events. They should agree within plus or minus three degrees with the events stamped on the name plate. The timing diagram is given at Fig. 689 C. Check the valve timing of cylinder 6R. The events of this cylinder should follow the corresponding events of cylinder 1L by approximately 60 degrees (between 58 degrees and 62 degrees).

When everything is satisfactory the engine is ready to be "closed up." Be sure there are no cotter pins left out of the nuts for the camshaft bearings. Be sure all cotter pins and lock wires are tight before putting the cylinder head (camshaft) covers on. Make certain that the lock screws of the cam followers are tight and that the covers are clean. It is recommended that the camshafts, valve springs, cam followers, and gears be "painted" with clean cylinder oil Put plenty of oil on Pour about half a pint of cylinder oil into each camshaft driveshaft housing, then assemble the cylinder head cover. The L.H. cover will not go on with the tachometer drive adapter in place. Tighten the screws for the covers and then screw the tachometer drive adapter in place. Put all covers on the gearcase except that for the starter deck. Place the distributor blocks and breaker assembly covers in place and lock them. If the starter clutch or "dog" was removed put it back in place on the crankshaft gear. Be sure it cannot loosen. Pour at least one quart of cylinder oil in the engine, making sure that the pocket containing the lower vertical shaft is full. Put on the starter or the cover for the starter deck. Put in the exhaust sparkplugs. The intake plugs should already be in place. Assemble the water manifold on the water jackets and connect them to the water pump. Use new hose if necessary. Be sure the hose clamps are in good condition. Instructions for installing and running the engine will be found in the chapter to follow on "Installation." The tabulations that follow are a summary of clearances for the Curtiss Model D12 series engines.

SUMMARY OF CLEARANCES

June, 1927

Model D12 Series Engine **List No. C-4492**	*Min.*	*Desired*	*Max.*	*Allowable before Replacing or Re-Adjusting*
Breaker Gap—Splitdorf Magneto	.020		.024	
Breaker Gap—Splitdorf VA-1 Magneto...........	.005	.006	.008	

SUMMARY OF CLEARANCES

Model D12 Series Engine List No. C-4492	Min.	Desired	Max.	Allowabl before Replacin or Re-Adjustin
Breaker Gap—Scintilla Magneto, Model AG-12D (VAG-12D)	.012		.015	
Cam follower—Dia. Clearance in Guide	.0005	.0015	.0025	.004
Camshaft—Diametrical Clearance	.0015	.0020	.0030	.005
Camshaft—End Play	.001	.005	.009	
Camshaft Driveshaft Ball Bearings—Dia. Clearance in Housing	.0003	.0007	.0016	.004
Camshaft Driveshaft Lower Bearing in Housing—End Play	.0018	.0038	.0098	.025
Crankshaft- Dia Clearance in Bearings	.0015		.002	.005
Crankshaft—Ball Thrust Bearing Outer Race End Play in Crankcase	.0005	.0005	.0035	.006
Crankshaft—Oil Retaining Collar—Dia. Clearance in Crankcase	.006	.0065	.012	.025
Connecting Rod—Dia Clearance on Crankpin	.0015		.002	.005
Connecting Rod—End Play on Crankpin	.002	.009	.016	.040
Connecting Rod (Short) End Play on Master Connecting Rod	.004	.006	.008	.012
Distributor Drive Intermediate Shaft—Dia. Clearance (D-12-F only)	.0010	.0020	.003	.005
Distributor Drive Intermediate Shaft—End Play (D-12-F only)	.005	.007	.010	.015
Distributor Driveshaft—Dia. Clearance (D-12-F only)	.0010	.0020	.0030	.005
Gears (All) Backlash when cold	.003	.005	.010	.020
Gear Gas Pump Driveshaft—Dia Clearance	.0005	.0010	.0013	.003
Gear Gas Pump Driveshaft—End Play	.002		.004	.010
Gun Control Driveshaft Ball Bearings—Dia Clearance in Housing	.0003		.0016	.004
Gun Control Driveshaft Upper Ball Bearing—End Play in Housing	.0018	.0038	.0098	.025
Gun Control Driveshaft Dia. Clearance in Housing	.001	.003	.006	.010
Gun Control Driveshaft End Clearance at top of Housing	.005	.013	.025	.040
Gun Control (E-4) Operating Plunger—Dia Clearance	.001	.002	.003	.004
Gun Control (E-4) Operating Plunger—End Clearance on Cam	.002	.003	.004	.006
Magneto Oldham Coupling Driving Flange Dia. Clearance in Housing	.008	.010	.012	.025
Magneto Driveshaft Ball Bearings—Dia. Clearance in Housing	.0003		.0016	.004
Magneto Driveshaft—Ball Bearing End Play in Housing	.002	.004	.010	.025
Oil Pump Line Shaft—Diametrical Clearance	.0005	.0010	.0015	.005
Oil Pump Gears—Dia. Clearance in Body	.004	.005	.006	.015
Oil Pump Gears—End Play in Body	.002	.003	.005	.01
Oil Pump Gears—Dia Clearance on Idler Shaft	.001	.002	.002	.00
Piston at Top Land	.017	.019	.021	.02
Piston at Bottom of Skirt	.010	.012	.014	.02
Piston Pin in Piston	.000	.001	.001	.00

SUMMARY OF CLEARANCES

Model D12 Series Engine

List No. C-4492

		Desired	*Max*	*Allowable before Replacing or Re-Adjusting*
Piston Pin in Connecting Rod	0005	.0015	002	.004
Piston Ring in Groove	0015	.0015	.0035	.005
Piston Ring Gap	007	.008	.009	.020
Propeller Hub—Dia. Clearance at Small End of Crankshaft when pushed on shaft by hand	002		004	.006
Pumps Driveshaft—Dia. Clearance in Gearcase	001	.002	.003	.006
Pumps Driveshaft—End Play in Gearcase	006	.010	.014	.025
Sparkplug—Gap (BG)	.014	.015	016	.030
Sparkplug—Gap (AC)	.022	.023	.024	.040
Tachometer Driveshaft—Dia. Clearance	.0010	.0020	.0030	.005
Tappet—Gap	.014	015	.016	.018
Valve—Diametrical Clearance in Guide	.0025	003	.004	.006
Vertical Driveshaft Ball Bearing—Dia. Clearance in Housing	001	0012	.003	.006
Vertical Driveshaft—Dia. Clearance at Lower End	.001	.002	.003	.006
Vertical Driveshaft—End Play in Gearcase	.007		.010	.025
Water Pump Shaft—End Play	.003		.006	.010
Water Pump Shaft Ball Bearing—Dia. Clearance in Housing	0003	0007	.0015	.004
Wristpin—Dia. Clearance in Short Connecting Rod	.0000	0005	.0015	.006

Wristpin—End Play in Master Rod—End of Wristpin must not come closer than .005″ to straight edge laid across side of big end.

QUESTIONS FOR REVIEW

1. How fast does the crankshaft turn on Curtiss D12 engines?
2. What is the Curtiss D12 cylinder construction?
3. Outline main steps in dismantling Curtiss D12 engine.
4. Are D12 cylinder heads removable?
5. Outline inspection process for D12 crankshaft assembly
6. What kind of a fit should a wrist pin have in the piston?
7. What parts of the oil pump assembly need inspection?
8. How are D12 cylinder blocks assembled on the engine?
9. How is timing of D12 engine checked?
10. Outline Curtiss D12 piston clearances.

ENGINES IN INTERMEDIATE STAGE OF POST WAR DEVELOPMENT

Engine	Symbol	No. of Cyls	Hp.	R P M.	Weight	Lb. Hp.	B M E P	Comp. Ratio	Cooling and Type
Packard	1A-1116	12	282	1600	733 2	2 59	125.1	5 56 1	W. C Vee
Packard	1A-744	8	160	1600	541.8	3 02	119 5	5 02-1	W C Vee
Packard	1A-1237	12	300	1800	735 0	2 1	125 0	6 5 -1	W. C Vee
Packard	1A 825	8	200	1800	547 0	2 34	119.0	5 02-1	W. C Vee
Packard	1A-2025	12	550	1800	1142	2 02	132 17	5 08-1	W. C. Vee
Packard	1A-1500	12	510	2100	738	1 44	129 0	5 5 -1	W. C Vee
Packard	1A-2500	12	800	2000	1100	1 37	..	5 5 -1	W. C Vee
Wright	E 4	8	190	1800	480	2 5	122 0	5 35-1	W. C Vee
Wright	H-3	12	320	1800	620	1 93	127 0	5.5 -1	W C Vee
Wright	T 3	12	575	1800	1160	2 0	131 5	5.3 -1	W. C. Vee
Curtiss	K-12	12	375	2250	728	1.94	....	....	W. C Vee
Curtiss	K-6	6	150	1700	417	2 78	121 8	5 63-1	W. C Vertical
Curtiss	C 12	12	400	2250	698	1 68	131 3	5.5 -1	W. C Vee
Curtiss	CD-12	12	400	2000	704	1 76	129 0	5 37-1	W C Vee
Curtiss	C-6	6	160	1750	448.5	2.79	126 9	5 2 -1	W. C Vee
Curtiss	D 12	12	375	2000	693	1 84	133 8	5 3 -1	W. C Vee
Curtiss	V-1400	12	500	2100	655	1 31	139 0	5 5 -1	W. C. Vee

ENGINES OF 1928

Engine	Symbol	No. Cyls	Hp	R P.M	Weight	Lbs Hp	Comp. Ratio	Type
Curtiss . .	D-12 (H C)	12	460	2300	680	1 48	6 :1	W C Vee
Curtiss . .	V1550	12	600	2500	720	1 2	5 7 :1	W. C. Vee
Curtiss . . .	V G 1550	12	600	2500	840	1 4	5 7 :1	W C Vee
Curtiss	Hex	12	600	2400	1000	1 62	. . .	A C Hex
Packard	2A-1500	12	600	2500	780	1.3	5 1 1	W. C Vee
Packard Geared	2A-1500	12	600	2500	880	1 47	5 1 1	W C Vee
Packard . . .	2A-2500	12	800	2000	1179	1 48	5 .1	W. C. Vee
Packard Geared	2A-2500	12	800	2000	1380	1 73	5 :1	W. C Vee
Wright	J5	9	250	2000	510	2 1	5 2 :1	A. C Rad
Wright	R1750	9	525	1900	750	1 45	5 4 :1	A. C Rad
Pratt & Whitney	Wasp	9	450	2100	670	1 49	5 25 1	A. C Rad
Pratt & Whitney	Hornet	9	525	1900	750	1 43	5 25 :1	A. C Rad
Liberty	Inverted	12	430	1700	1015	2 36	5 4 :1	A C Vee
Liberty	Inverted	12	420	1700	900	2 14	5 4 :1	W C Vee

Note. The above tabulations refer to engines which have been used on U. S Army and Navy airplanes and do not include the numerous air-cooled engines that have been successfully used for commercial work. All the above are American engines.

CHAPTER XXXVIII

PACKARD WATER-COOLED AVIATION ENGINES

Packard Aircraft Engines—General Description of Engines—Crankcase Construction —Connecting Rods and Pistons—Cylinder Construction—Lubrication by Pressure Oil System—Return Oil System—Water Circulation—Avoiding Steam Traps in Circulating System—Oil Cooler—Ignition Distributors—Ignition by Independent Magnetos—Double Magneto Ignition—Scintilla Magnetos—Battery-Generator Ignition—Carburetion—The Oil and Water Pump Unit—Improvements in Model 2A-1500 Engines—Improvements in Model 2A-2500 Engines—General Specifications—Standard Adjustments—Standard Clearances—Unpacking Packard Engines —Preparing Packard Engines for Service—Starting the Engine—Starting with Battery Ignition—After the Engine Starts—Stopping the Engine—Care of Models 2A-1500 and 2A-2500 Engines—After Every 20 Hours—To Check Timing Without Disassembling—Grinding Valves Without Disassembling Cylinder Blocks—Summary of Operations for Complete Tear-Down of Engines—Re-assembling Engines —Crankshaft Plug Assembly—Removal of Cylinders from Valve Housing—Tappet Adjustment—Valve Grinding—Camshaft Timing Instructions—Battery Distributor Timing—Tools Furnished with Engine—Base Repair Shop Tools—Standard Types 2A-1500 and 2A-2500 Engines—Inspection of Gear Reductions—Lubricating System of Inverted Engine—Water Circulation of Inverted Engine—Carburetion of Inverted Engine—Packard 24-Cylinder X Engine.

Packard Aircraft Engines.—Two engines of 500 and 800 horsepower respectively have been recently developed by the Packard Motor Car Company for aircraft service. When these engines are compared with previous types they are found to be more compact and to produce more power per pound of weight. When each is operated at its rated speed, the Model 1,500 engine shown at Fig. 691 develops 100 horsepower more than the Liberty while weighing 140 pounds less, and the Model 2,500 engine develops 250 horsepower more than its predecessor, the Model 2,025, with a decrease in weight of 75 pounds. These improvements have been made possible largely because of a new type of cylinder construction, original studies with regard to the loads that can be carried by bearings, reduction of the weight of the crankshaft while at the same time strengthening it, and the compacting and lightening of the timing and accessory-drive layout. Other improvements were made in the lubricating system and in the design of the valve gear and springs.

The novel cylinder construction which has been previously described enables the cylinders to be spaced closely together and the weight of the whole engine to be diminished. Other advantages incorporated into the design include water circulation in close contact with the heated surfaces, the use of a steel cylinder barrel as a wearing surface that carries the explosion loads down to the crankcase, the locating of the hold-down flange some distance from the end of the cylinder barrel so that the ends of the barrels of the cylinders of the two banks can practically be allowed to touch inside the crankcase and the engine can be run in an inverted position. Mr. L. M. Woolson has stated that the complete weight of the Model 1,500 cylinder is but 9.5 pounds and the cylinder develops nearly 50 horsepower. The weight of the Model 2,500 cylinder is 15.2 pounds and the cylinder

develops 70 horsepower. The front end view of the Model 2A-1,500 inverted engine is shown at Fig. 692 A and a side view at Fig. 692 B.

Still other features comprise improved types of valve-housing and valve gear layout; positive cooling of the exhaust valve by oil pumped through it, a special type of multiple cluster small diameter piano wire valve spring, simplicity in the grouping of the accessories; a special type of magneto having a single magnetic circuit and two independent electrical circuits, either one of which will fire all twelve cylinders; the possibility of replacing magneto ignition with battery ignition by substituting a generator for the magneto but without other change to the engine or to the wiring between

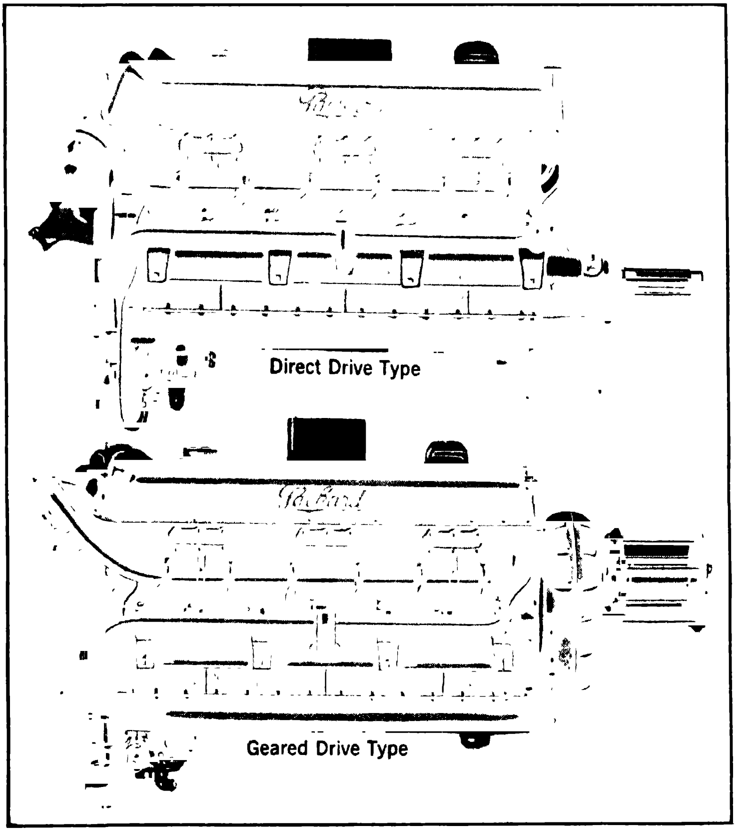


Fig. 691.—Packard Model 2A-1500 Aircraft Engines. Direct Drive Model at Top. Geared Drive Shown Below It.

the distributors and the sparkplugs; the use of very short, comparatively light, rugged slipper-type pistons; and the ability to use either direct drive or gear reductions. In applying these facts to commercial aviation, these comparative performances mean that the new engines can carry double the pay-load over the same distance or the same pay-load 2¼ times as far as could their progenitors.

The pistons of both the Model 1,500 and the Model 2,500 engines are of special interest in that they are of the slipper-type and are very short and comparatively light, although of rugged construction. The Model 1,500 piston is $3\frac{11}{32}$ inches long and weighs 2.94 pounds; the Model 2,500 piston is $3\frac{15}{16}$ inches long and weighs 4.47 pounds, bare. The smaller piston is $5\frac{3}{8}$ inches in diameter and has only 90 per cent of the weight of the

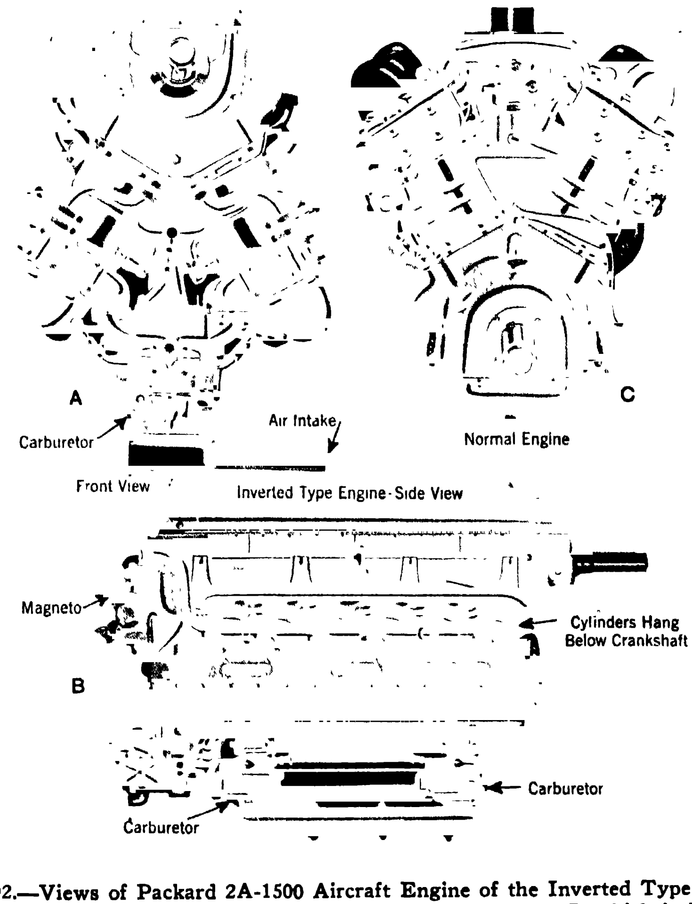


Fig. 692.—Views of Packard 2A-1500 Aircraft Engine of the Inverted Type Shown at A and B. Compare Carburetor Location with that Shown at C, which is Front End of the Same Engine Used in the Conventional Manner. Changes Necessary to Run Engine Inverted are Described in Text.

Liberty piston although having fifteen per cent more area; the larger piston is $6\frac{3}{8}$ inches in diameter and has 63 per cent of the weight of the Shenandoah engine piston although having only nine per cent less area than the latter. The lengths of these new pistons were established after a series of tests in which the length of the skirt was gradually diminished.

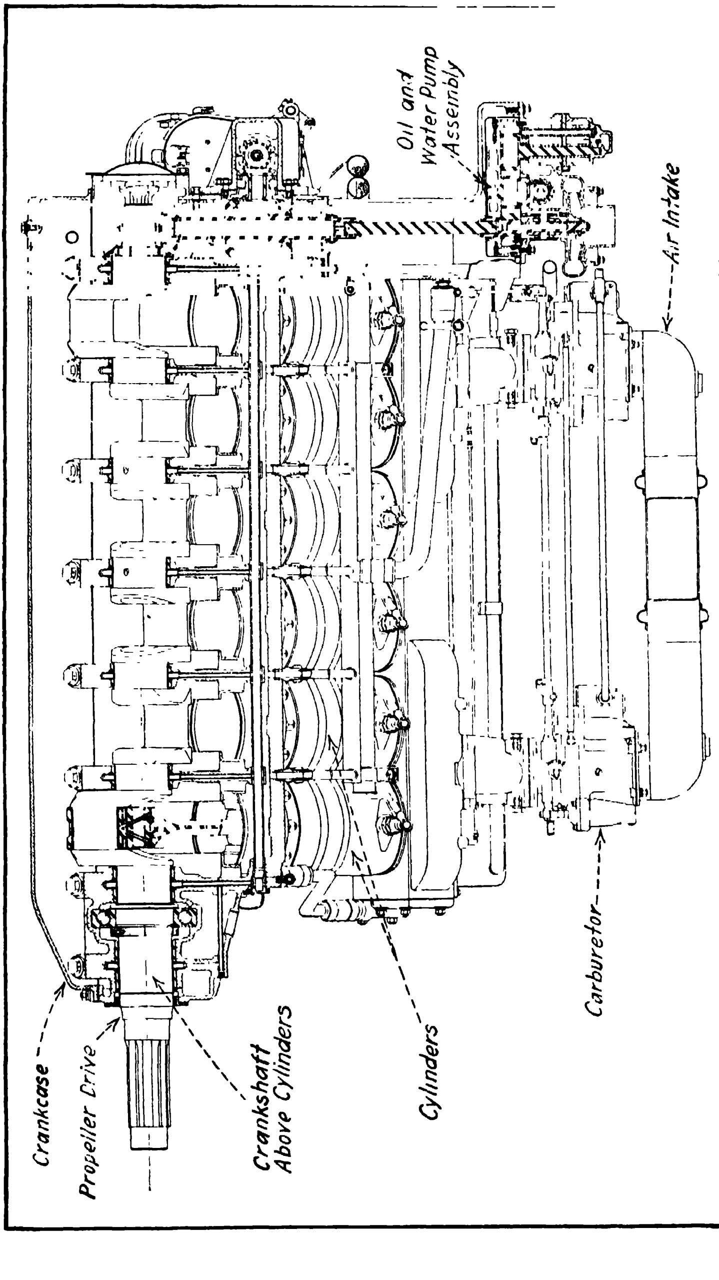


Fig. 693.—Longitudinal Section Through Packard Aircraft Engine, Model 2A-1500 Inverted.

As a result of investigating the relation of bearing materials to allowable speeds and loads, it was ascertained that failures of aircraft bearings rarely occur because of lack of lubrication or of wear but are caused by fatigue of the babbitt lining produced by minute flexing of the back of the bearing. Tests showed that the limitations of the bearings could be raised provided they could be prevented from flexing under load and ample force-feed lubrication were provided. The PV values of the bearing loads adopted, as compared with those of the Liberty engine, are: for the crankpin, 18,520 pounds per square inch as against 13,200; for the center bearing, 35,000 as against 22,650; and for the intermediate bearing, 27,000 as against 14,000.

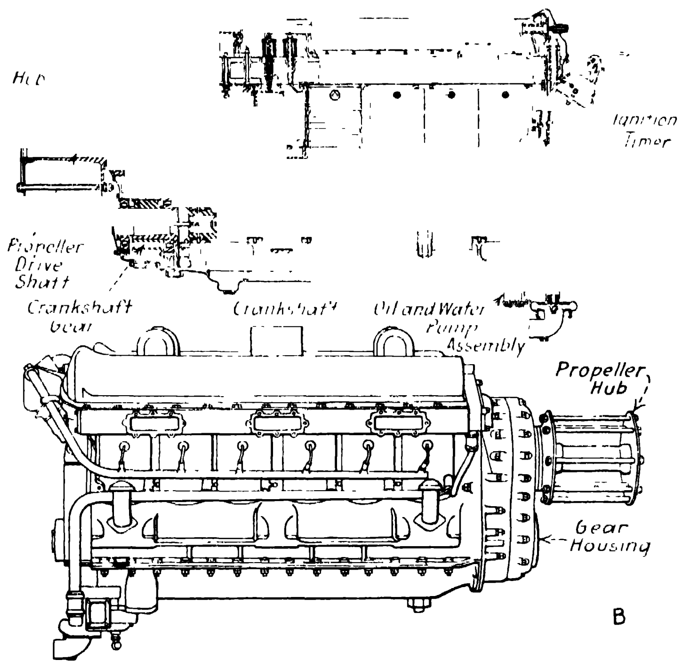


Fig. 694.—Longitudinal Section of Packard Aircraft Engine Model 2A-2500 Shown at A Depicts Important Parts, Especially Propeller Drive Gearing. External Appearance of the Same Engine Shown at B. This Engine Develops 800 Horsepower.

The critical speed of vibration of the Packard crankshaft is 64 per cent higher than that of the Liberty; it is also twice as stiff as well as weighing 30 per cent less, a feature accomplished by the use of journals having comparatively large outside diameters but bored out through their centers.

The crankcases of both engines are of particularly rugged design, great depth being obtained partly because of the design of the cylinder and partly because of the arrangement of the main bearings. The eight main bearings as shown at Fig. 693 which shows a longitudinal section of the inverted 2A-1,500 engine are of steel-backed babbitt construction, the upper half being doweled to the crankcase and the lower half to the forged duralumin

bearing caps that are accurately fitted in longitudinally machined ways in the transverse webs of the crankcase. With this construction, in a Vee-type engine, the main bearing bolts are relieved of bending stresses imposed by the explosion loads. The thrust bearing is of the deep groove radial ball bearing type and is located between two plain bearings in the front bearing cap. The lower half of the crankcase is an aluminum stamping that serves merely as an oil pan and supports the combined pump unit by a generous flange.

The propeller hub is of the taper-fit type on the smaller engine and carries a forged-duralumin loose flange which, it should be noted, is not keyed or otherwise located on the propeller hub, a construction that has proved perfectly satisfactory in flight tests as well as in overload propeller-whirling tests. On the larger engines a splined hub with split centering cones is used.

Although both the 500 and the 800 horsepower engines were originally intended for direct drive service, both have been built for use with gears, the gear reduction forming a separate unit bolted to a special crankcase flange. The gear reductions have been designed and built by the Allison Engineering Company of Indianapolis. They are of the spur-gear single reduction type and are entirely self-contained. A noteworthy feature is the employment of a shock-absorbing drive between the crankshaft and the pinion that has proved very successful in eliminating the gear trouble resulting from impact loading. Fig. 694 A shows the sectional side view and Fig. 694 B the side view of the 800 horsepower geared engine. These gear reductions give a two-to-one reduction to the propeller shaft that has been found to be particularly desirable for load-carrying airplanes of moderate speed. In addition to providing improved propeller efficiency, these geared engines lend themselves particularly well to a streamline installation; and, in this manner, improved propeller efficiency and decreased resistance combine to offer important advantages in airplane performance. The 500 horsepower engine has also been built in the inverted type and, an inverted engine has many advantages for aircraft use. It is entirely possible that the future will see the inverted engine as one of the standard types. A side view of the inverted Model 1,500 engine is shown in Fig. 692 B, and a front view in Fig. 692 A. A longitudinal sectional view is shown at Fig. 693.

General Description of Engines.—The models 1,500 and 2,500 Packard aircraft engines are of practically identical design and construction and differ only in their relative sizes. These engines are of the 60 degrees Vee, twelve-cylinder, water-cooled type having a rating of 525 brake-horsepower at 2,100 r.p.m. and 600 brake-horsepower at 2,500 r.p.m. for the smaller engine and 800 brake-horsepower at 2,200 r.p.m. for the larger engine The model 2A-1,500 engine has twelve cylinders, 5⅜-inch bore and 5½-inch stroke, and the model 2A-2,500 engine has twelve cylinder, 6⅜-inch bore and 6½-inch stroke. Detailed specifications of the two engines will be found in proper sequence and cross-sectional views at Figs. 693 and 695.

The cylinder construction is a composite design possessing the advantages of both the unit type and block cast in respect to the ease of replacement of individual cylinders of the former type of construction and the

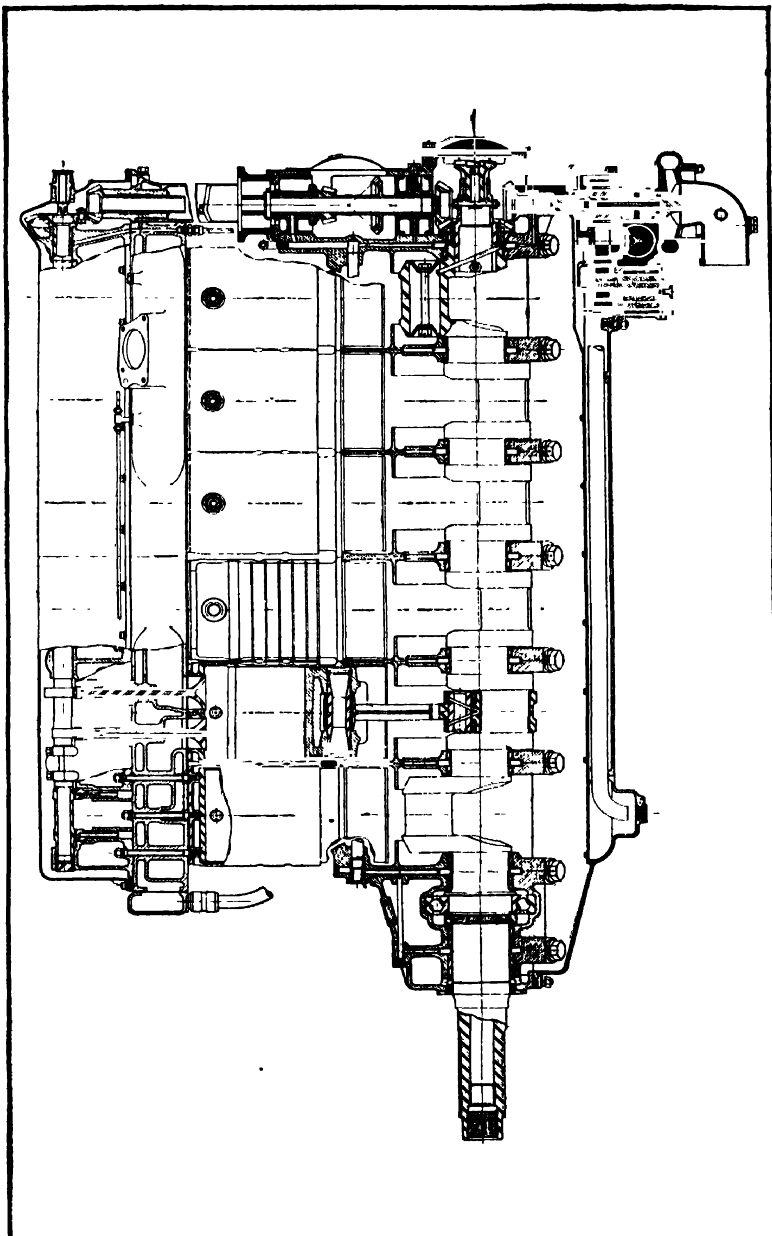


Fig. 695.—Longitudinal Section Through Packard Aircraft Engine Model 2A-1500 Direct Drive, Showing Cylinder Construction Method of Valve Actuation by Overhead Shaft.

general rigidity and cleanliness of design of the latter type. The cylinder and valve housing assembly is mounted on the engine as a unit and should be removed in the same manner.

Crankcase Construction.—The crankcase of the model 2A-1,500 engine shown at Fig. 695 is of modified box section type, the main bearing upper halves being supported in the transverse webs of the crankcase upper half and the main bearing lower halves being supported in bearing caps. A special feature in connection with the model 2A-1,500 crankcase construction lies in the fact that the bearing caps are attached to the crankcase by means of long through bolts, the upper ends of which pass through crabs which engage the cylinder hold-down flange. Each pair of main bearing bolts is arranged with an included angle of 60 degrees, the bolts being

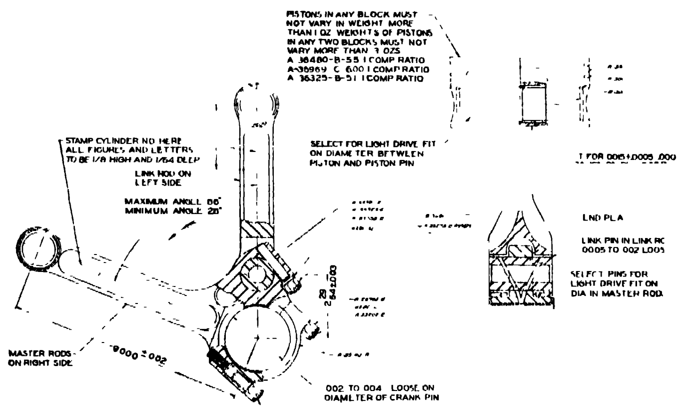


Fig. 696.—Connecting Rod Assembly of Packard Aircraft Engine Model 2A-1500 Showing Clearances.

parallel to the cylinder axis and the bolting surfaces between the bearing caps and the crankcase upper half are square with the axis of the bolts, thus giving a wedge-like appearance to the bearing caps and contributing greatly to the stiffness and rigidity of the structure. With this arrangement the explosion loads are carried from the cylinder to the main bearing caps practically entirely through steel bolts, the crankcase walls serving as compression members.

The crankcase on the model 2A-2,500 engine is of the conventional box section type, the main bearings being supported in the seven transverse webs of the crankcase upper half, the bearing caps being supported by massive studs arranged vertically and screwed into the crankcase upper half. The crankcase finish surface, to which the oil pan is bolted, is brought down 2½ inches below the centerline of the crankshaft, the object being firstly to add rigidity to the crankcase structure; secondly, to render the oil pan attaching screws and nuts more accessible. The bearing caps are duralumin forgings except in the case of the front and rear caps which are cast of a special heat treated aluminum alloy. The main bearings are of babbitted steel-backed construction and are doweled to both the bearing cap

and the crankcase upper half. The main bearings are provided with force feed lubrication, oil being delivered through a horizontal manifold pressed in the crankcase upper half and distributing through vertical tubes leading to each bearing pressed in the crankcase transverse walls. The oil pan or crankcase lower half serves as a mounting for the combined water and oil pump unit and is provided with a screen extending its full length to protect the pump unit from being damaged by foreign particles in the oil. The oil pan is provided with a scavenging line leading to the front end and serving to keep the crankcase scavenged on a glide. The oil pan can be removed from the engine at any time without disturbing the engine bearings.

Packard Crankshafts.—The crankshafts in both engines follow customary aircraft engine practice and are noteworthy for their rigidity, the main journals of the two engines measuring three inches and 3¼ inches in diameter respectively, and the crankpins are 2½ inches and 3¼ inches in diameter respectively. Both main journals and crankpins are bored out with large holes and the crankpins are plugged to provide an oil reservoir for leading oil to the crankpin journals These reservoirs receive oil from the adjacent main bearings by means of steel tubes pressed into the crankshaft at an angle and lining up with the main bearing metering grooves at one end and the crankpin bore at the other. The main bearing metering grooves are located entirely in the upper half of the main bearings, extending twenty degrees around their circumference on the model 2A-1,500 engine and 30 degrees around their circumference on the model 2A-2,500 engine.

Connecting Rods and Pistons.—The connecting rods of both the model 2A-1,500 and 2A-2,500 engines are of the articulated type fitted with babbitt bearings applied directly to the big end of the connecting rod, as shown at Fig 696. The piston pin bushings in the connecting rods are of phosphor bronze and the same material is used in the link pin bushings. The link pins are retained in place by a tapered draw bolt passing through a boss on the master rod.

The pistons of both engines are aluminum castings of the permanent mold type and are of slipper design. Pistons of different compression ratios can be furnished to suit varying requirements. Three rings of the concentric type with diagonal slots are fitted above the piston pin and the lower ring groove is fitted with an oil drain relief provided with drain holes leading through the piston walls. The lower ring is also ground with a three degree taper relief to act as an oil scraper ring. The piston pins are allowed to float in both the connecting rod upper and the piston pin bosses, endwise movement being limited by snap rings sprung into grooves in the piston pin bosses.

Cylinder Construction.—The cylinders are of all-steel construction and are provided with a hold-down flange located some distance above the lower end of the barrel. The upper end of the cylinder terminates in a flat ground surface to which the valve housing is bolted by means of five long studs fastened to the cylinder head. A copper-asbestos gasket is interposed between the cylinder head and the valve housing. The cylinder construction

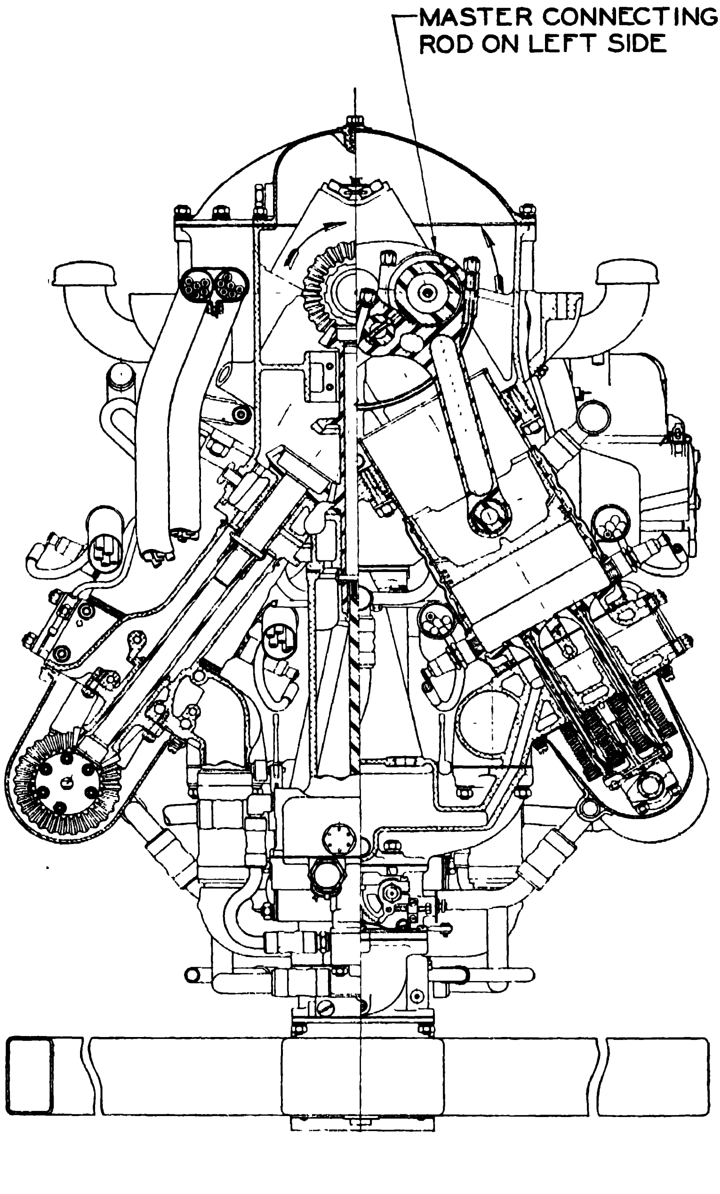


Fig. 697.—Transverse Section Through Packard Aircraft Engine, Model 2A-1500 Inverted.

is unique in that it provides for water in contact with all heated surfaces, the cylinder head being of a double plate construction with water space between the two plates. This is shown in the cylinder section at the right side of Fig. 697. The valves are seated against the inner surface of the lower plate so that the cylinder head gasket referred to is not subjected to explosion pressure. Circulating water is delivered to the individual cylinders by means of a manifold connected to the individual water inlet connections at the base of the cylinder. The water is discharged through the valve housing through holes provided in the cylinder top plate referred to, suitable ferrules in the copper-asbestos gasket insuring delivery of the

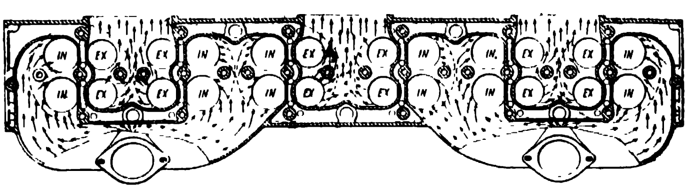


Fig. 698.—Sectional View of Packard Valve Housing Showing Location and Porting of Valves, Four Valves Being Used for Each Cylinder.

water to the valve housing through corresponding holes in the valve housing lower surface. These holes are provided in the cylinder around the exhaust ports only so as to favor the distribution of water over the hottest parts of the cylinder head. The cylinders are provided with two sparkplug bosses which are machined out of stock integral with the combustion-chamber forging and a sheet metal water jacket is welded to the cylinder at the flange provided near the lower end of the barrel and to the top plate. A single longitudinal welded seam completes the jacket.

The valve housing is an aluminum casting machined on all surfaces and used interchangeably on the right and left hand banks. The housing performs the following functions and is shown diagrammatically at Fig. 698:

(1) Distributes the mixture to the six cylinders from the two carburetor cross header manifold connections.

(2) Forms the exhaust passages, each two adjacent cylinders having their two pairs of exhaust ports siamesed into a single exhaust outlet.

(3) Collects the water circulated through each cylinder jacket and delivers same through a single outlet at the front of the engine.

(4) Supports the camshaft bearing pedestals and valve stem guides.

The valve housing is turned end for end for use on the opposite bank of cylinders, the water outlet connections at the front end and the camshaft drive housing at the rear end being suitably drilled so that no change is required in the valve housing itself, thus making it necessary to carry only one type of spare housing in stock. However, it is necessary to plug certain holes at the front or water outlet end of the valve housing. The holes to be plugged are the vertical and horizontal oil pressure connection and one stud hole on the model 1,500 engine and two stud holes on the model 2,500 engine for which no corresponding holes are provided in the water outlet connection.

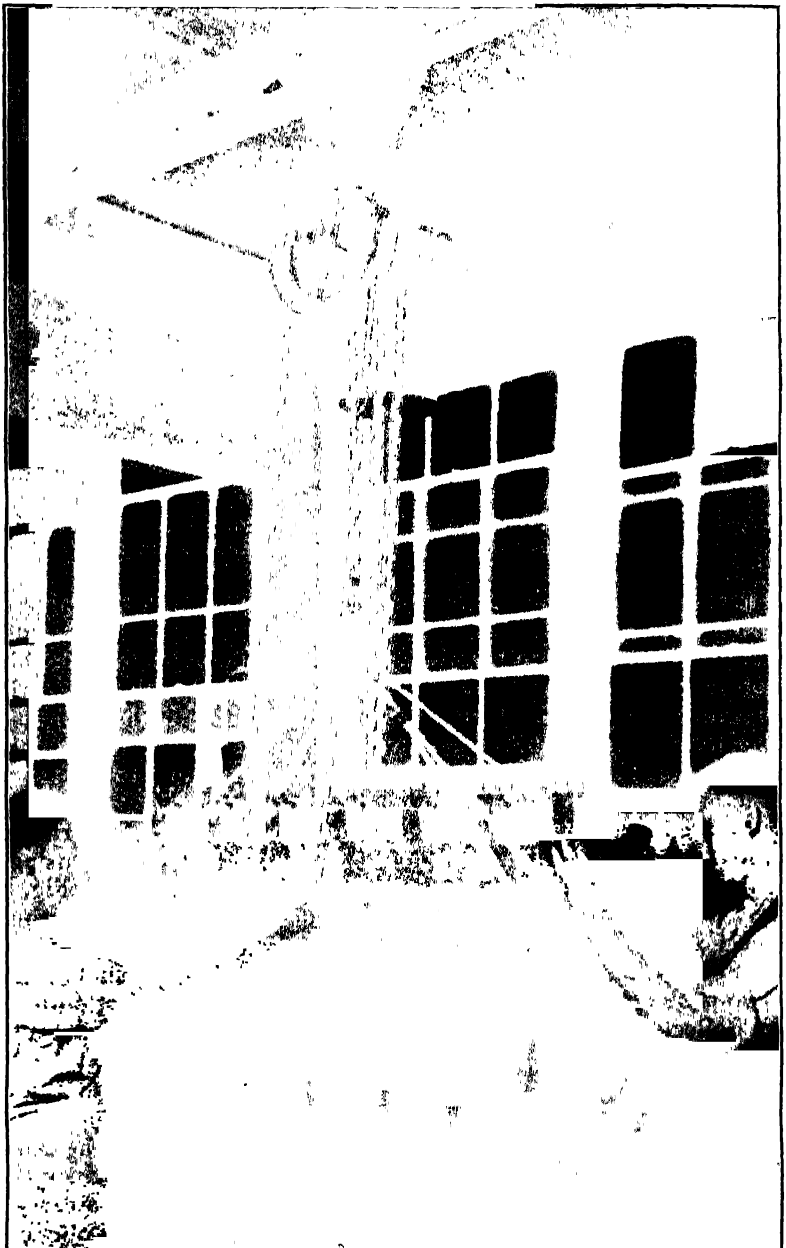


Fig. 699.—Photograph Showing Method of Lifting a Cylinder Block Off of Packar
Aircraft Engine Model 2A-2500.

The valve housing is united to the six individual cylinders to form a cylinder block by means of 30 long studs $\frac{5}{16}$ inch in diameter for the 1,500 engine and $\frac{3}{8}$ inch in diameter for the 2,500 engine. Furthermore, two studs from each cylinder are used to hold down the camshaft bearings, these bearings being located accurately in line by means of hollow dowels engaged in counterbores in the top surface of the valve housing. The inlet and exhaust valve guides have a light press fit in the valve housing and it is essential that a good fit be maintained at this point especially in respect to the inlet valve guides to prevent oil leaking into the inlet ports around the outside of the valve guides. The method of handling a cylinder block as a unit is shown at Fig. 699.

The front and rear camshaft bearings are fastened to the valve housing by three studs each, one of which is a cylinder hold-down stud and the other two are special studs for securing these bearings in place. The camshaft bearing at the gear end is provided with a vertical passage and an annular groove communicating with same for the purpose of introducing oil into the hollow camshaft at this point, the camshaft being suitably drilled. The cam followers operate in reamed bosses formed integral with the camshaft bearings and the cam followers are restrained from turning by reason of their flat surfaces engaging a flat surface provided on each camshaft bearing. The camshaft bearings are lubricated by means of oil holes provided in the camshaft in approximately the center of each bearing, and the lubrication of the cam followers is carried out in one manner for the inlet cam followers and in another manner for the exhaust cam followers. Half-round grooves are provided in the inlet camshaft bearings which lead the oil escaping at the end of the bearings to the top of the cam follower stem guide, this oil flowing over all cam follower working surfaces. The exhaust cam followers are lubricated by the same means which conduct oil to the exhaust valves for cooling purposes.

This has been shown diagrammatically and fully described in a preceding chapter. It consists of a vertical passage in the exhaust camshaft bearing which registers with a hole in the camshaft located radially with respect to the adjacent cam so that oil from the camshaft flows down this passage when the nose of the cam is at its highest point, or in other words, when the corresponding exhaust valves are closed. This vertical passage communicates with a horizontal milled passage in the base of the exhaust camshaft bearing which leads to each exhaust cam follower guide hole. The exhaust cam followers are drilled both vertically and horizontally and the tappets are also drilled. The exhaust valve stems are hollow and fitted with a $\frac{3}{16}$-inch steel tube which is pressed into a necked-down section of the valve stem at the upper end and is brazed to a $\frac{1}{8}$-inch pipe plug at the lower end through which this tube is inserted. Three horizontal holes are drilled near the lower end of the tube and the valve stem proper is provided with two horizontal holes just below the necked-down portion. In this manner oil introduced under pressure at the upper end of the valve stem flows down inside the tube out through the holes at the base and up around the outside of the tube to the two outlet holes in the valve stem. When the camshaft revolves the exhaust cam depresses the cam follower and the oil which is trapped in the cam follower guide is forced through the exhaust

valves in the manner indicated, thus cooling the valves and greatly prolonging the period between valve grinding operations.

Lubrication by Pressure Oil System.—The same lubrication system is employed on both the models 2A-1,500 and 2A-2,500 engines. The same oil pumps are used on both engines and the oil circulating means are the same in both cases. Both engines operate on the dry sump principle, using an external oil tank and oil cooler. Oil is led up to the pressure oil pump through the oil "in" line (1¼-inch O. D. tube connection) located at the bottom of the oil pump body. The oil flows through a fine mesh screen which is readily accessible by removing the hexagon head screw holding the oil strainer cover in place on the left side of the oil pump. After flowing through the oil screen the oil is led into the pressure pump and is forced out either through a pressure line leading to the engine bearings or past a relief valve and through the oil "out" connection leading back to the tank In the model 2A-2,500 engine a fine mesh screen is also provided on the discharge side of the pressure pump, the suction screen on this model engine being of coarser mesh. Oil under pressure is led to the oil manifold extending the full length of the engine and located at the top of the crankcase by means of passages provided in the oil pump body and crankcase oil pan These passages consist of steel tubes pressed in the aluminum castings and "matched" joints are provided between the oil pump body and the crankcase oil pan and between the oil pan and crankcase respectively.

Care should be taken that clear holes are provided in the gaskets at these two points to prevent an obstruction to the oil supply reaching the engine Vertical tubes are pressed into each crankcase main bearing wall, these tubes communicating with the horizontal manifold referred to. It should be noted that all of these oil connections are permanently pressed in place, preventing the possibility of loose connections developing in service. The main bearing upper halves are drilled and furnished with hollow dowels which permit the oil to flow through the metering groove provided in these bearings. Steel tubes are pressed into the crankshaft and terminate at one end in the main journals in line with the bearing metering groove and at the other end communicate with the hollow crankpins. These crankpins are plugged at both ends by means of duralumin plugs locked together with a through bolt and an oil feed hole is drilled in the crankpin to lead the oil to the connecting rod bearing. A connection for the oil gauge line is provided at the front end of the crankcase, thus registering the lowest oil pressure in the system. At the rear end of the crankcase a tube is provided which terminates in a ¼-inch internal pipe thread into which is screwed a tee provided with connections for the two oil lines leading to the camshaft housings.

The timing gear bearings are lubricated by oil passages, each bearing being positively fed from the main lubricating system. The camshafts are lubricated through oil passages leading through the rear end of the valve housing and through a matched joint between the rear camshaft bearing and the housing. This rear camshaft bearing is provided with a continuous groove and the oil flows into the camshaft through two holes provided in the camshaft in line with this groove. The camshafts are hollow and

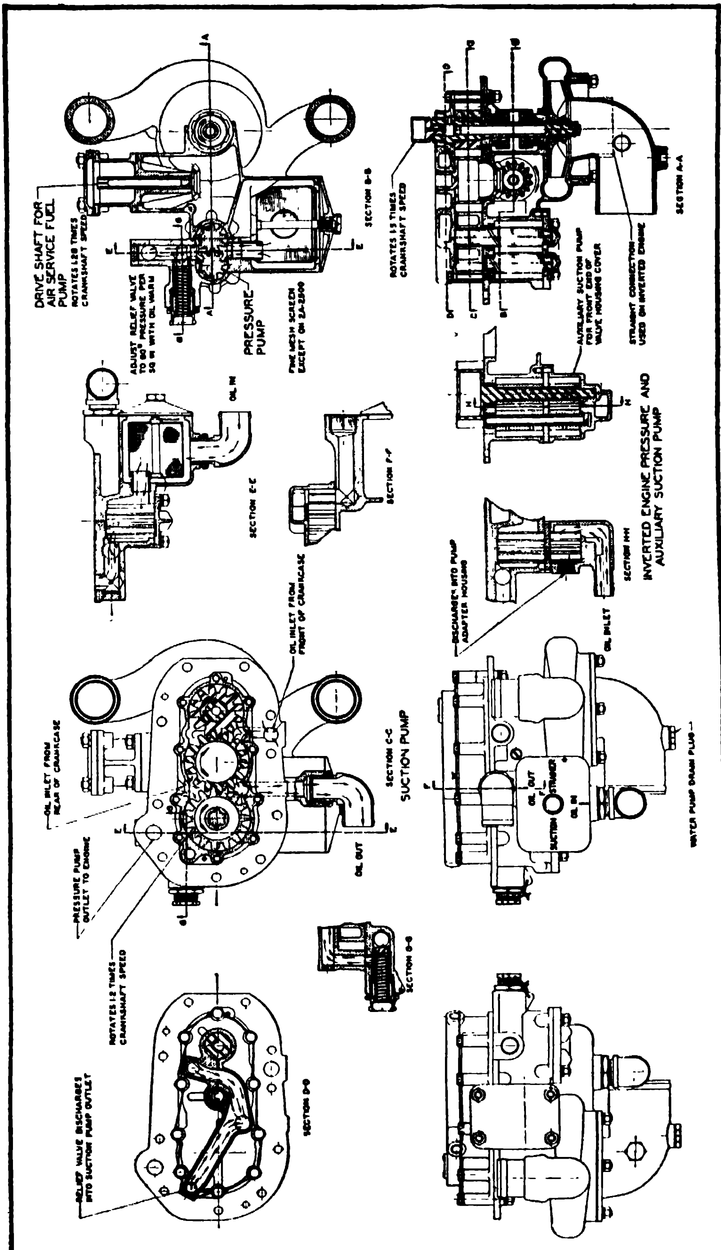


Fig. 700.—Assembly of Packard Aircraft Engine Oil and Water Pump Units for Models 2A-1500 and 2A-2500.

plugged at both ends and have oil holes specially located in the bearing adjacent to the exhaust cam followers so as to register with vertical passages in these particular camshaft bearings at such time as the toe of the adjacent exhaust cam is at its highest point, that is, 180 degrees from the valve wide-open position. In this manner oil under pressure flows through the camshaft and through the camshaft bearings and into the cam follower guide.

Return Oil System.—The excess oil thrown from the connecting rod and main bearings after lubricating the pistons collects in the lower half of the crankcase or oil pan. The oil thrown out from the camshaft bearings and the oil pumped through the exhaust valves collects in the valve housing compartment and drains back to the oil pan through drains provided both at the front and rear of the engine. When the front end of the engine is high, as in a plane with the tail on the ground or when climbing, the oil from the valve housing compartment returns to the crankcase through generous cored holes provided in the upper camshaft drive housings. This oil together with the oil returned from the various timing gear shaft bearings flows through two oil traps provided in the horizontal web extending across the timing gear compartment just above the crankshaft. The purpose of these oil traps is to prevent crankcase vapors, consisting of products of combustion which have leaked by the pistons, from rising into the timing gear and camshaft compartment and causing rusting of these parts due to condensation. After flowing through these oil traps the oil collects in the oil pan. When the front end of the engine is low, as in gliding or diving, the oil from the camshaft housings flows to the front end of the crankcase through the oil return tubes provided on the outside of the engine at the forward end.

The oil which collects in the oil pan or sump passes through the screen which covers the entire bottom portion of the oil pan and is returned to the outside oil tank by means of either or both oil scavenging pumps provided in the pump unit. These two scavenging pumps are formed by enclosing the three spur gears which are mounted respectively on the water pump shaft, the fuel pump driving shaft and the pressure pump shaft. The intermediate and forward or oil pressure pump driving gear combined form a scavenging pump which drains the rear end of the crankcase, the oil flowing to this pump through a hole provided in the gear cover of the scavenging pumps. The intermediate and the rear gear which is mounted on the water pump shaft combine to form a scavenging pump for the forward end of the crankcase, a pipe being clamped to the bottom of the oil pan and extending to a small sump at the front end of the oil pan for the purpose of collecting this oil and delivering it to the rear scavenging pump through suitable passages formed by a matched joint between the pump unit body and the crankcase oil pan flange. The combined oil and water pump assembly is shown at Fig. 700 and all the parts disassembled at Fig. 701.

External Oil System.—Two 1¼-inch hose connections are provided on the oil pump for the "oil in" and "oil out" connections respectively, these markings being cast on the oil strainer cover so as to indicate the purpose of the two connections. The oil should be led through a suitable oil cooler with a distance thermometer placed preferably in the circuit before the o

passes through the cooler, but in any case, the thermometer should be distinctly marked as to whether it indicates "oil in" or "oil out" temperature. The oil cooler or regulator should have a cooling surface of about 25 square feet for the model 1,500 engine and about 40 square feet for the model 2,500 engine, and it is important that this oil cooler should be built amply strong to withstand 150 pounds per square inch pressure which may be encountered during the first few minutes of running with an engine with congealed oil in extremely cold weather. The oil cooler should also have suitable drains for draining both the oil and water (if used) sections.

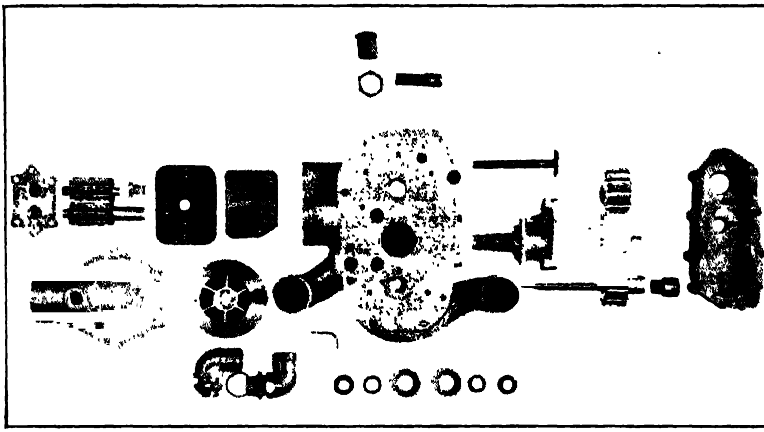


Fig. 701.—Parts of Oil and Water Pump Assembly of Packard Aircraft Engines.

The oil should be discharged into the external oil tank near the top of same, and this oil tank should have a capacity of between 1/10 and 1/12 of the gasoline capacity of the plane, this value excluding an allowance for expansion amounting to an additional ten per cent of the volume. The lowest part of the oil tank should be preferably arranged to be slightly higher than the inlet connection to the oil pump.

The top of the oil tank should be vented to either of the connections provided at the rear end of the crankcase or at the front, whichever may be more convenient, this vent pipe being not less than ½-inch O. D. and the piping being as direct as possible, avoiding any low points in which congealed oil might collect in cold weather. The lowest point on the oil tank should be connected to the "oil in" connection on the oil pump unit by means of a ¼-inch O. D. pipe. Special care should be used to insure that all external oil pipes be as direct as possible and free from sharp bends, and a suitable drain should be provided at the lowest point in the system. Where the oil lines between the oil tank, oil cooler and the engine are necessarily long they should be water jacketed for their entire length and this procedure is also advisable even when the lines are short so as to promote the flow of oil when in a congealed condition by means of hot water circulated by the engine.

Water Circulation.—The water circulation system through the models 1A-1,500 and 2A-2,500 engine follows conventional practice. Water is de-

livered to the inlet of the water pump through an elbow connection or a vertical connection as required by means of a 2½-inch I. D. hose fitting over the elbow connection which can be attached to the pump at any of six different positions. The water pump forms part of the oil pump unit shown at Figs. 700 and 701 and is of the centrifugal type, is driven at 1½ engine speed, and delivers approximately 100 gallons of water per minute at 2,000 r.p.m. through an unrestricted external system. The water pump body is provided with two outlets, one to each bank of six cylinders, and external steel manifolds conduct the water to the individual inlets near the base of each cylinder. The water flows upwards through the jackets, entirely surrounding the cylinders, and completely covers the combustion-chamber head. Holes are provided surrounding the exhaust ports leading the water through the copper-asbestos gasket into the valve housing. Individual water outlets are provided at the front end of the valve housings, these being adapted to receive 1¾-inch I. D. hose for both the model 2A-1,500 and 2A-2,500 engine.

When installed in a plane so that the engine is either level or with the propeller end high the entire water system can be drained by removing the plug provided in the water pump inlet elbow.

Avoiding Steam Traps in Circulating System.—With a conventional nose radiator installation, in which an expansion tank is built into the radiator and receives water from the engine by vertical rising connections, there is practically no danger of steam pockets forming in the system if ordinary care is used to insure the system being full of water and free from any air pockets. With the growing tendency towards using tunnel radiators or other types of radiators mounted below the engine great care must be used to avoid forming steam traps in the system. The one infallible rule to follow is that steam will always rise to the highest point in the system and can rarely be induced to flow downhill. Therefore in any cooling system employing a radiator, the inlet of which is below the top of the engine, it is essential to provide an expansion tank and this expansion tank must be piped to the water outlet connections of the engine by pipes which lead continually upward when the engine is in a level flying or climbing position. Under gliding or diving conditions this precaution is, of course, not essential. Where the engines are operated as "pushers" special vents are provided in the camshaft drive housings and these vents should be led to the highest point in the water system with no loops or horizontal runs.

Tapped bosses are provided on both right and left hand water outlet connections to receive standard distant-type thermometer bulbs. A single thermometer on each engine is considered sufficient and should be mounted on the instrument board in the usual manner, but in the case of a dual controlled machine it may be advisable to provide a separate instrument for each cockpit.

Oil Cooler.—The most preferable form of oil cooler is of the water-tube type. It is essential that the water circuit through this cooler be as direct and unrestricted as possible in order not to throttle the water pump capacity at high speeds. In laying out the water system it should be borne in mind that the piping should be as direct as possible as sharp bends introduce high resistances.

Ignition.—Three alternative forms of ignition can be applied to either the model 2A-1,500 or model 2A-2,500 engines, dependent upon the service requirements. These three types are the following: 1. One double magneto mounted in Vee with two independent distributor drives. 2. Two twelve-cylinder magnetos carried on a bracket bolted to the rear end of the crankcase as shown at Fig. 702. 3. Battery generator ignition furnished by two distributors mounted in inclined position at the rear end of the engine in conjunction with a generator mounted vertically in the Vee or horizontally at the rear end of the crankcase.

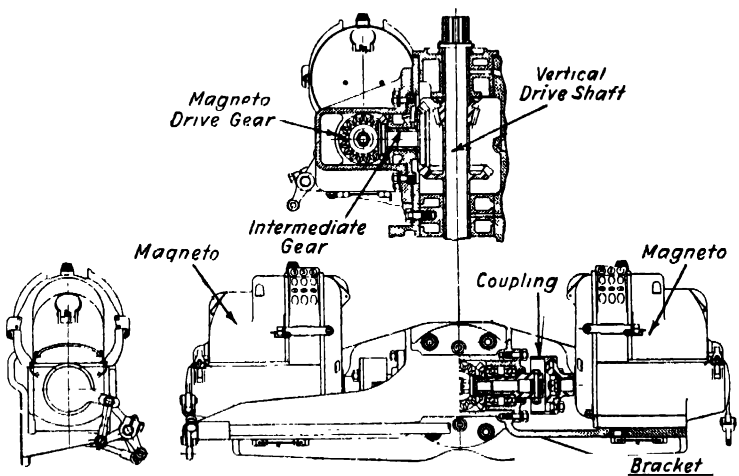


Fig. 702.—Magneto Drive Assembly of Packard Aircraft Engines, Models 2A-1500 and 2A-2500.

Distributors.—Distribution of the high tension current to the two sets of sparkplugs is accomplished by two independent but interchanged distributors driven respectively off of each camshaft driveshaft at one-half engine speed. The distributors are timed in substantially the same fashion as the battery distributors with the exception that the rotors are arranged exactly opposite to the center of the radially arranged distributor terminal at such time as the magneto contacts are just separating with the magneto advance lever in the midway position between "full-advance" and "full-retard." It will be noted that the distributors when used in conjunction with the double magneto are locked in position and are connected to the advance lever control as in the case of the battery distributors. The proper synchronizing of the high tension rotors with the magneto interrupters as outlined above is essential for the satisfactory operation of the engine as lack of this synchronism may make the engine difficult to start and also cause missing at high speed. A connection is provided on the distributor cap for a booster magneto high tension connection. This terminal is provided on either distributor and connects with a trailing brush on the rotor by means of an insulated ring set inside the distributor block. Each distributor on both the models 2A-1,500 and 2A-2,500 engines fires all twelve cylinders, the left

distributor being wired to the inside or inlet sparkplugs and the right distributor being wired to the outside or exhaust sparkplugs.

Ignition by Two Independent Magnetos.—In installations requiring the use of two independent magnetos these instruments are mounted horizontally on a bracket bolted to the rear end of the crankcase. The magnetos are driven at one and one-half times engine speed through adjustable couplings. The drive is furnished by a bevel spool gear meshing with an integral bevel gear provided on the camshaft center driveshaft. Both magnetos turn in the same direction, viz., counter-clockwise facing the driving end of the magneto. Approximately correct timing relationship is established by meshing the proper teeth on the bevel pinion driving the magneto and a fine adjustment is secured by clamping the two halves of the adjustable coupling in the correct position. The following are the recommended settings:

	High Compression	Low Compression
Model 2A-1,500 engine	35 deg. adv.	40 deg. adv.
Model 2A-2,500 engine	44 deg. adv.	50 deg. adv.

Note: The above settings are to be made with the spark advance lever in the full advance position.

The magneto contacts should be adjusted to show a gap of from .012 inch to .016 inch at the time of maximum opening. The low tension terminal on each magneto is to be connected to the corresponding terminal on the ignition switch, and the high tension booster magneto connection should be connected preferably to the left hand magneto which is used to fire the inside or inlet sparkplugs. The right hand magneto is wired to fire the exhaust or outside sparkplugs. The advance arms on the two magneto breaker boxes are interconnected by a control shaft and levers furnished with the engine, and the bell crank provided on the left hand end of this control shaft should be connected to the spark advance control in the pilot's cockpit.

Double Magneto Ignition.—The magneto is mounted vertically in the Vee at the rear end of the engine and is driven at one and one-half times engine speed from the extension of the lower camshaft driveshaft. The two high tension distributors are independent units driven by bevel gears off the camshaft upper driveshafts in the same manner that the battery-generator distributors are driven and mounted. A single high tension wire connects each distributor with the corresponding high tension terminal on top of the magneto. The magneto is of the inductor type with a revolving four-pole rotor and two sets of stationary windings. A four-lobed cam is mounted on the upper end of the rotor shaft. The driving member of the coupling is in approximately correct timed relationship to the engine and the exact setting of the spark is secured by rotating the magneto bodily on its slotted flange, the two $\frac{5}{16}$-inch hold-down nuts being tightened when the desired setting is obtained. The following are the recommended settings:

	High Compression	Low Compression
Model 2A-1,500 engine	35 deg. adv.	40 deg. adv.
Model 2A-2,500 engine	44 deg. adv.	50 deg. adv.

Note: The above settings are to be made with the spark advance lever in the full advance position. The magneto contacts should be adjusted to show a gap of from .010 inch to .012 inch at the time of maximum opening.

The two low tension terminals on the terminal block on top of the magneto are to be connected to the corresponding terminals on the special ignition switch furnished with this magneto and it is very important that these connections maintain good electrical contact. The two high tension terminals are connected to the distributors and care should be taken to prevent these wires from fouling the controls, gun synchronizers, or any other moving parts.

Scintilla Magnetos.—Contact Breaker Mechanism:—The life of the contact points depends to a great extent on how clean they are kept. Take particular care that no oil, gasoline, kerosene or foreign matter gets on them. The contact points should not be filed unless absolutely necessary. The gap between the contact points should be maintained in accordance with the gauge on the Scintilla wrench. The thickness of this gauge is 012 inch. To remove the contact breaker assembly, move the breaker to midway position between full advance and full retard positions. Bring the bayonet lock hand latch to the same vertical position and pull out the breaker assembly. Oiling the Magneto:—Place 30-40 drops of oil in the front oil holes or until it appears at the overflow hole which is located about two inches below the timing window. Put about five drops of oil in the back oil hole. Use the best grade of medium-bodied machine oil. The magneto should be oiled about every 25 hours. Assembling the Magneto:—This should be done with the utmost care. See to it that the rotating magnet is absolutely free of filings, chips, etc. Match up parts marked "D" when magneto is clockwise rotation. Match up parts marked "G" when magneto is anti-clockwise rotation. If it is necessary to change the rotation of the magneto, we advise that it be returned to the Scintilla factory.

Timing the Magneto to the Engine.—The numbers on the top of the main cover are for the purpose of locating the distributor blocks to their proper sides. The letter H marks the terminal to which the booster wire is to be connected. The letter P marks the terminal to which the ground or short circuiting wire is to be connected. The arrow indicates the direction of rotation of the magneto viewed from its drive end. The numbers on the distributor blocks show the firing order of the magneto.

No. 1 on the distributor gear can be seen through the timing window located under the front oil hole cover. When this No. 1 corresponds with the white mark at the top of the timing window, it indicates that the contact points are just opening with the breaker fully advanced. Some installations do not permit of this window being seen, and in such cases the marks on the inside surface of the distributor gear corresponding to marks on the inside surface of the front end plate should be used.

Battery-Generator Ignition.—This form of ignition is supplied by two special Delco distributors driven at one-half engine speed by bevel gears meshing with integral pinions cut on the right and left hand camshaft upper driveshafts. Distributor Instructions: Synchronize Contact Arms—Loosen contact plate hold-down screws. Turn adjusting eccentric until

both arms break contact at the same time. Tighten hold-down screws.

Contact Separation.—.014 inch to .016 inch.

Contact Spring Tension.—18 to 22 ounces.

Manual Advance.—60 degrees.

Bearings and Lubrication.—One annular ball bearing and one roller bearing. Place eight to ten drops of medium engine oil in the oil hole in the top of the cam every sixteen to twenty flying hours.

Each distributor contains two low tension interrupters connected in parallel and operated in synchronism by a twelve-lobed cam. A sleeve extension of this cam is slotted off center and drives a moulded rotor arm which distributes the high tension current received through the center brush. A condenser is mounted inside the distributor casing and is readily detachable. An eccentric adjustment is provided on the breaker arm supporting plate to permit of synchronizing the two breakers and it is important that both sets of interrupter contacts are separated at substantially the same time. An ignition coil which is not mounted on the engine is furnished with each distributor, and the two coils should preferably be located as close as possible to the distributors but in a relatively dry and cool location well protected from excessive vibration. In most installations the fire wall immediately back of the engine is suitable for the purpose, and the coils should be securely mounted by means of four bolts passing through the bosses provided on the coil. Nine millimeter high tension cable is to be used to connect the high tension terminal on the coil to the center terminal on the distributor and this wire should be as short and direct as possible with sufficient allowance to take care of the weaving of the engine in the mounting. It is advisable to "safety" the high tension connection on the coil by means of a piece of safety wire passed through a hole drilled through the high tension terminal. It is advisable to cover this terminal with rubber tape protected by a final layer of friction tape to minimize the danger of water reaching the high tension terminal.

One primary connection on the coil should be connected to the primary terminal on the distributor with extra flexible primary wire of No. 12 or No. 14 size. Terminals of approved design are to be securely soldered to each end of this wire and sufficient length should be provided to insure free operation of the distributors throughout the entire range from full-retard to full-advance. Two types of ignition coils are furnished; one in which the resistance unit is mounted on the ignition switch, as in the Liberty ignition system; and the other in which the resistance unit is mounted on the ignition coil. It is very important that only one resistance unit should be in the circuit, as if there should be a resistance unit on the switch as well as on the coil the current will be greatly weakened and it will be impossible to operate the engine at anything approaching full throttle. If, on the other hand, no resistance should be employed either on the switch or on the coil, excessive current will be used and the coil will be seriously damaged or completely burned out in a very short time and the ignition interrupter contacts will also suffer serious damage.

The two distributors are advanced and retarded together by means of a connecting rod fitted with ball and socket joints at each end. It is important that both distributors be synchronized especially in the full advance

position and the length of this connecting rod can be changed to effect this adjustment by means of the screw threads provided at either end.

Generator Test—Hot.—Start 1,400 r.p.m. Nine amperes at 2,500 and 3,500 r.p.m. Maximum twelve amperes.

Note: Above readings taken at generator. If generator is tested Cold add three amperes to above readings.

To Adjust Charging Rate.—Turn adjusting nut on end of generator counter-clockwise to increase and clockwise to decrease charging rate.

Brush Spring Tension.—1-1¼ pounds on each.

Cut-Out Relay.—Contacts close 12½-14 volts. Separate with 0-3 amperes discharge. Gap between core and armature with contacts closed .040-.047 inch. Gap may be adjusted by slightly bending the armature stop. To raise cut-in voltage, increase spring tension or increase gap. To lower cut-in voltage, decrease gap and if necessary slightly decrease spring tension. To decrease discharge current, increase spring tension and decrease gap.

Bearings and Lubrication.—Annular ball bearings. Place eight to ten drops of light engine oil in each oiler every six to eight flying hours.

Rotation.—1½ engine speed, clockwise facing commutator end.

Ignition Wire Identification.—Each ignition wire has affixed to it a small metal tag at the distributor end with the number of the cylinder ranging from one to six, the position right or left shown by "R" or "L," and inlet or exhaust side of the cylinder shown by "I" or "E." Furthermore, on Scintilla model AG-12D magneto installation the order of firing of each individual sparkplug, ranging from one to twelve, is shown by an additional number on the tag corresponding to the markers employed on the Scintilla distributors.

Carburetion.—Both the model 2A-1,500 and 2A-2,500 engines are provided with two Stromberg carburetors and the carburetors are bolted to an air intake and to their respective cross intake manifolds so as to form a complete unit which can be detached from the engine by removing the nuts bolting the manifolds to the valve housings, disconnecting the throttle and mixture control rods and breaking the gasoline line at the rear hose connection provided at the rear end. The carburetor, manifolds and air intake assembled for each engine are shown in the photograph at Fig. 703 B. The intake manifolds are heated by means of exhaust gases circulated through a jacket surrounding each manifold. The exhaust gas is drawn from Nos. 1 and 2 and 5 and 6 exhaust ports by means of drilled passages provided for that use and these gases are finally drawn into the intake manifold to mix with the fresh mixture going into the cylinders through the two ⅛-inch orifices provided on each manifold. With this arrangement the volume of exhaust gas drawn through each manifold varies in proportion to the vacuum existing in the intake manifold. That is to say, when the engine is idling or turning over at moderate speeds the vacuum is quite high, resulting in a comparatively large volume of exhaust gas passing through the jacket and thereby helping to warm the engine up quickly when starting up preparatory to a flight or on a glide. On the other hand, when the throttle is wide-open the vacuum is low and very little exhaust gas is drawn through the manifold and consequently the mixture is not overheated to the detriment of full power operation.

Model 2A-1,500 Engine.—The model 2A-1,500 engine is equipped with two duplex Stromberg carburetors of the NA-Y6P type. The standard settings for these carburetors on this engine are as follows:

Choke	$1\frac{1}{8}''$
Main jet	No. 40 drill
Idle metering jet.....	No. 61 drill
Idle air bleed........	No. 50 drill

For detailed instructions regarding this carburetor refer to special chapter on Stromberg carburetors. It will be noted that the cross header connecting the two cylinder blocks with each carburetor is not provided with any partition so that both halves of the duplex carburetor feed any of the six

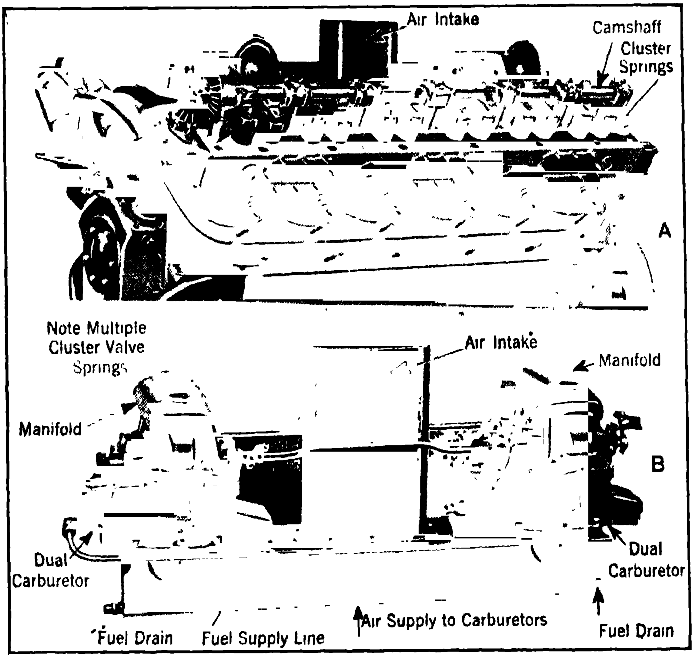


Fig. 703.—View at A Shows Packard Valve Gear with Overhead Camshaft and Multiple Cluster Springs. B Shows Carburetor Joined to Common Air Intake Castings with Vertical Intake Stack. Each Carburetor Carries an Induction Pipe by Which it is Coupled to Valve Housings.

cylinders supplied by each cross header. This facilitates adjusting the carburetors for idling since it is no longer necessary to give the idling adjustment a separate setting for three cylinders at a time since six cylinders are controlled by the same adjustment.

Synchronizing screws are provided in the connecting shaft between the two carburetor throttle shafts and these should be so adjusted that the front carburetor throttle closes slightly in advance of the rear carburetor so that when the pilot puts a very slight strain on the throttle control both carburetor throttle sectors will come smartly against their respective idling stops.

Model 2A-2,500 Engine.—The model 2A-2,500 engine is equipped with two special single Stromberg carburetors of the NA-S12 type. The standard settings for these carburetors on this engine are as follows:

Choke	$3\frac{1}{8}''$
Main jet	No. 36 drill
Idle Metering jet	No. 38 drill
Idle air bleed	No. 56 drill

For detailed instructions regarding this carburetor refer to instruction book issued by the manufacturer and accompanying each engine and also the chapter on carburetors. The idling adjustment on the model 2A-2,500 is even simpler than on the 2A-1,500 engine as each carburetor has only one adjustment. The throttle connecting rod between the two carburetors should be adjusted so that the forward carburetor closes slightly in advance of the rear carburetor but so that a further slight pressure will bring the rear throttle against its stop also.

Both the model 2A-1,500 and 2A-2,500 engines are equipped with pistons giving different compression ratios according to the service required. The compression ratio for any particular engine is stamped on the name plate, and in case of doubt reference should be made to this identification. In general, engines with five to one compression ratio can be operated quite satisfactorily on domestic aviation gasoline. The model 2A-1,500 engines equipped with the 5 5 to 1 compression ratio can be operated on domestic aviation gasoline under conditions not requiring sustained full throttle operation near sea level. If continuous full throttle operation under these last conditions is required it is advisable to blend the domestic aviation gasoline with about twenty per cent benzol, which must be of suitable purity and free from sulphur. An equivalent anti-knock can be obtained using five c.c. of ethyl fluid to each gallon of domestic aviation gasoline. With the model 2A-2,500 engines employing 5.5 to 1 compression ratio or higher, and with the model 2A-1,500 engines employing compression ratios of 5.7 to 1 or higher, it is advisable to use a blend of 40 per cent benzol and 60 per cent domestic aviation gasoline, or ten c.c. of ethyl fluid per gallon of domestic aviation gasoline.

The Oil and Water Pump Unit.—The pump unit is shown in section at Fig. 700. This unit is used interchangeably on both the models 2A-1,500 and 2A-2,500 engines and consists of: A single casting which comprises the water pump body, oil pressure pump body, strainer compartment, and mounting for the relief valve and fuel pump. A gear cover which encloses three spur gears which drive the various units. This gear cover acts as a scavenging pump body for the two scavenging pumps for the front and rear crankcase drainage systems. The pump unit is attached to a flange on the crankcase lower half or oil pan by means of ten $\frac{5}{16}$-inch studs and is driven from a short shaft journaled in the rear main bearing cap and provided with an integral bevel gear, meshing with the crankshaft gear, through a full-floating Oldham coupling. The pump is driven at $1\frac{1}{2}$ times engine speed in a counter-clockwise direction. The coupling drives the water pump shaft directly and on the upper end of this shaft a steel spur gear is fitted for driving the other units.

The water pump shaft is provided with two stuffing boxes, the upper one to prevent oil in the crankcase from leaking out along the shaft and the lower one to prevent water from leaking upwards around the pump shaft. A locking strip engages milled slots in the stuffing box adjusting nuts and serves to lock the nuts when the desired adjustments have been made. These nuts can be tightened by being pried around by a blunt-ended screwdriver and when being adjusted should be tightened as far as possible and then backed off to the nearest locking slot. Both packing glands are automatically lubricated from oil in the crankcase which flows down the hollow pump shaft and out through the small hole provided opposite each gland. The water pump impeller is keyed to the tapered end of the water pump shaft and is provided with a threaded hub to fit a special puller provided in the tool kit for the purpose of removing the impeller when necessary. In assembling the impeller on the shaft, care should be used to see that the impeller does not rub against the walls of the body or cover, but is located with approximately the same clearance on either side. The steel gear on the water pump shaft meshes with a steel gear which carries on the extension of its integral shaft a bevel pinion meshing with a similar bevel pinion driving the fuel pump.

The oil pressure pump consists of a pair of duralumin gears, the driving member of which is fitted with an integral splined shaft extension on which is pressed a duralumin spur gear meshing with the intermediate steel gear driving the fuel pump. The oil pressure pump communicates with the strainer compartment by means of a bored passage and a screen is arranged between the "oil in" connection and the pressure pump inlet. The screen is made in box form fitted with a cover and can be readily withdrawn by loosening the screw mounted on the center of the cover plate. This plate is located on the pump unit by means of a dowel on the right hand side and care should be used in replacing the cover to line up correctly with the dowel. A vellumoid gasket is placed under the cover and should be examined before replacing the cover plate.

The model 2A-1,500 engine is provided with a fine mesh (No. 30) screen on the suction side of the pressure pump as described above and the model 2A-2,500 engine is equipped with a coarse mesh (No. 12) screen in the same location. The model 2A-2,500 engine, however, carries in addition a fine mesh screen (No. 50) provided with an automatic bypass valve mounted integrally on the screen and this unit is built into the crankcase lower half on the larger engine, the oil first passing through the coarse mesh screen, then through the pressure oil pump and then through the fine mesh screen before passing on to the bearings. It is, of course, very important that the fine mesh screen (No. 30) should always be employed on the suction side of the model 2A-1,500 engine pressure pump as the use of a coarse screen on this engine would permit dangerously large particles of dirt to pass through the lubricating system. The oil pressure relief valve is located in a horizontal position extending forward on the right hand side of the pump unit. To raise the oil pressure the adjusting screw should be turned to the right and to lower the oil pressure it should be turned to the left. After any change in adjustment the jam nut should be securely tightened. An oil pressure of about 75 pounds is desired with the oil hot at an engine speed of about 1,500 r.p.m.

Improvements in the Model 2A-1,500 Engines Over the Model 1A-1,500 Engines

Crankcase and Main Bearings.—In order to meet the requirements of extreme high-speed running a radically new form of crankcase construction and main bearing support has been worked out in the model 2A-1,500 engine. The long through main bearing bolts located parallel to the two banks of cylinders replace the conventional arrangement of two vertical studs supporting the main bearing caps in the model 1A-1,500 engines. These long bolts assist in holding the cylinders to the crankcase by means of crabs engaging the cylinder hold-down flanges.

Cylinders.—In the 2A-1,500 engines the cylinder head has been increased in overall depth by ⅛ inch, this representing additional water space between the combustion-chamber and top plate, the extra depth yielding about a 35 per cent improvement in rigidity.

Timing Gears.—Changes have been made improving the accessibility of the driving gear train. The camshaft center driveshaft can now be removed through the top of the crankcase, whereas previously it was necessary to dismantle the engine to remove this shaft. The camshaft drive side gear upper housings can now be removed from the valve housings without removing the cylinder block, thus permitting the removal of the entire gear train without disturbing the cylinder blocks or taking an engine out of a plane in the ordinary installation.

Gasoline and Oil Connections.—The oil "in" and "out" connections on the model 2A-1,500 engines are made to receive 1¼ inch I.D. hose connections instead of the one inch connections used on the model 1A-1,500 engines. The oil "in" connection has been changed from the front of the strainer compartment to the underside to simplify the piping on the average plane installation. The oil gauge connection is formed by a ¼-inch hose nipple integral with a two-bolt flange fitting provided on the left rear motor support arm. The gasoline connection (except when the Wright Viking pump is used) is formed by a ½-inch hose nipple integral with the two-bolt flange fitting provided on the rear crankcase wall on the right hand side.

The object in enlarging the oil "in" and oil "out" connections is to obtain freer flow of oil in cold weather. The purpose in providing the hose connections fór the oil pressure lines and the gasoline lines is to avoid failures of these important lines in service. It is felt that the ideal piping layout consists in having these lines terminate at suitable hose connections on the fire wall or some fixed part of the structure adjacent to the rear of the engine and have short direct copper lines with the hose connections at each end to connect up with the corresponding engine lines.

Ignition Distributor Drives.—The ignition distributor drives have been removed from the center of the camshaft and are now driven off the camshaft drive side gear upper. This change was made in order to remove the influence of the torsional oscillations of the camshaft from the distributor shaft, a much smoother drive being obtainable in the new position. The new location is also preferable from the standpoint of avoiding oil leaks around the distributor mounting.

Carburetor Air Intake.—The removal of the distributors from the center of the engine has permitted the installation of a centrally located air intake stack. In this connection the two carburetors and manifolds and the carburetor air intake with throttle and altitude controls and connecting gasoline lines can be withdrawn from the Vee as a unit, this greatly simplifying the assembly and disassembly of the engine.

Oil Pump Screen.—A screen extending the full length of the oil pan is now provided, effectively preventing any foreign particles from reaching the two oil scavenging pumps and at the same time presenting sufficient surface to avoid the necessity for cleaning except at long intervals.

Connecting Rods.—The model 2A-1,500 engines are equipped with articulated connecting rods of similar design to that used on the model 1A and 2A-2,500 engines in place of the straddle rod construction used on the model 1A-1,500 engines. It has been found that the articulated rod construction offers a more rigid backing for the bearing (which is now of babbitt directly applied to the connecting rod) essential for continued high-speed operation.

Carburetion.—The model 2A-1,500 engine is equipped with two Stromberg NA-Y6P carburetors with a throttle bore of $2\frac{7}{16}$ inches, as compared with the NA-Y5 carburetors having a throttle bore of $2\frac{3}{16}$ inches used on the model 1A-1,500 engine. In addition to the increased capacity obtained with the larger carburetor modifications in the float chamber construction and location of the gasoline passages permit the new carburetors to continue to function in the violent maneuvers required in pursuit work.

Exhaust-Heated Intake Manifolds.—A very important improvement in the model 2A-1,500 engine consists in the application of exhaust heat to the intake manifolds, thus greatly improving acceleration with a cold engine, economy at cruising speeds, and elimination of snow formation on the throttle. This exhaust heat is applied in a somewhat similar fashion to the fuelizer on Packard cars. That is to say, the supply of heat varies inversely as the throttle opening as the flow of exhaust gases through the jacket is determined by the vacuum existing in the intake manifold, the exhaust gases being used to dilute the charge at idling and cruising speeds. At full throttle, owing to the low vacuum prevailing in the intake manifold, practically no exhaust gases are drawn through the jacket so as to avoid detrimental overheating with loss of power and possible detonation.

Improvements in the Model 2A-2,500 Engines over the Model 1A-2,500 Engines

Cylinders.—In the 2A-2,500 engines the cylinder head has been increased in overall depth by ¼ inch, which yielded about a 50 per cent improvement in rigidity.

Timing Gears.—As in the model 2A-1,500 engines, changes have been incorporated which permit the entire timing gear train to be removed without removing the cylinder blocks or taking the engine out of a plane in the ordinary installation.

Gasoline and Oil Connections.—The oil "in" and "out" connections on the model 2A-2,500 engine are made to receive 1¼ inch I. D. hose instead of the one inch I. D. hose connections employed on the model 1A-2,500

engines. The oil "in" connection has been changed from the front of the strainer compartment to the underside to simplify piping on the average plane installation. The oil gauge connection is formed by a ¼-inch hose nipple integral with a two-bolt flange fitting provided on the left rear motor support arm as in the 2A-1,500 engines. The gasoline connection (except when the Wright Viking pump is used) is formed by a ⅝-inch hose nipple integral with the two-bolt flange fitting provided on the rear crankcase wall on the right hand side.

Ignition Distributor Drives.—As in the 2A-1,500 engines, the model 2A-2,500 engine ignition distributor drives have been removed from the center of the camshaft and are now driven off the camshaft drive side gear upper.

Oil Pump Screen.—The 2A-2,500 engines are provided with a screen extending the full length of the oil pan which prevents foreign particles from reaching the two oil scavenging pumps. In addition to the screen extending over the oil pan an additional pressure screen with a self-contained bypass valve is mounted in a compartment formed in the oil pan or crankcase lower half, this screen being located between the oil pressure pump and the oil pressure manifold feeding the bearings

Carburetion.—The model 2A-2,500 carburetors are practically identical with the model 1A-2,500 carburetors except for slight changes in settings.

Exhaust-Heated Intake Manifolds.—The intake manifolds are provided with exhaust-heated jackets similar to the model 2A-1,500 engines as described above. The provision for a passage for this exhaust gas to the manifolds necessitated revised valve housings incorporating four-bolt flanges for attachment to the manifolds instead of two-bolt flanges used on the 1A-2,500 engines.

Crankcase Upper to Lower Half Studs.—The studs uniting the upper and lower half of the crankcase were increased to ⅜ inch to provide a more rigid attachment replacing the $^5/_{16}$ inch studs employed on the 1A-2,500 engines.

In order to provide a passage for the exhaust gas to the intake manifold jacket it has been necessary to revise the valve housings on the model 2A-1,500 engine, a four-bolt flange being used for the attachment of the intake manifold as compared with the two-bolt flange used on the model 1A-1,500 engine.

Rating.—The model 2A-1,500 engine, having successfully completed a 50-hour Navy endurance test with wide-open throttle at 25 r.p.m., is rated at 600 horsepower at 2,500 r.p.m. or 525 horsepower at 2,100 r.p.m. The model 1A-1,500 engines should not be run at sustained speeds in excess of 2,100 r.p.m.; and the model 2A-1,500 engines should not be run at sustained speeds in excess of 2,500 r.p.m.

Improvements in the Model 3A-2,500 Engines over the Model 2A-2,500

Crankcase and Main Bearings.—Model 3A-2,500 crankcase and main bearing cap construction is similar to the model 2A-1,500 engine. The main bearing caps are attached to the crankcase by means of long through bolts, the upper ends of which pass through crabs which engage the cylinder hold-down flanges. Each pair of main bearing bolts is arranged

with an included angle of 60 degrees, the bolts being parallel to the cylinder axis and the bolting surfaces between the bearing caps and the crankcase upper half are square with the axis of the bolts, thus giving a wedge-like appearance to the bearing caps and contributing greatly to the stiffness and rigidity of the structure. With this arrangement the explosion loads are carried from the cylinder to the main bearing caps practically entirely through steel bolts, the crankcase walls serving as compression members.

Cylinders.—In the model 3A-2,500 engines, the exhaust valve seats are of Delhi Hard steel, and are pressed into the cylinder head and retained by having their upper ends expanded in boiler-tube fashion.

Magneto Mounting and Drive.—In model 3A-2,500 engines using two Scintilla magnetos for ignition, the magnetos are mounted on brackets formed integral with the crankcase, and the magnetos are driven through flexible adjustable couplings by short shafts carrying bevel pinions, meshing directly with the driving gear formed integrally on the camshaft center driveshaft. The short driveshafts are each mounted on two ball bearings. This construction dispenses with the separate magneto bracket formerly used, and results in a saving of weight and space as well as the elimination of the spool gear needed with the former construction.

Oil Pump Suction Strainer.—The oil suction strainer has been changed from the square-shaped screen used in former engines to a much larger cylindrical screen. Incorporated in the strainer housing is a spring-operated piston valve which automatically closes the passage leading from the "oil in" connection to the strainer compartment when the cover is removed for the purpose of cleaning or examining the strainer. When the cover is replaced, this valve is positively opened so as to restore the flow of oil. This permits the examination of the screen without draining the oil tank.

Oil Out Thermometer Connection.—The "oil out" elbow is furnished with a tapped boss to receive a standard theremometer connection, eliminating the necessity for providing a thermometer well in the "oil out" line.

Two-Way Oil Pressure Relief Valve.—The oil pressure relief valve has been modified by the addition of a small valve set in the head of the main valve and opening in the opposite direction. This auxiliary valve is maintained on its seat by a light spring and its purpose is to permit the flow of oil through the scavenging pump discharge line, back into the oil pressure manifold, whenever the pressure in the scavenging discharge line exceeds the pressure in the main pressure pump discharge line. This condition arises in very cold weather, when the scavenging pump builds up considerable pressure in attempting to force the oil remaining in the crankcase from previous running back through the oil cooler and into the oil tank. At the same time, the pressure oil pump suction line is usually filled with congealed oil when first starting up the engine, preventing the pressure oil pump from functioning during the first few minutes of cold weather running. Under these conditions, the auxiliary oil relief valve permits the scavenging pumps to serve as pressure pumps, so long as oil remains in the crankcase, and thus protects the engine during the warming-up period. In extremely cold weather it will be quite feasible to add oil to the crankcase through the breather to permit the scavenging pumps feeding oil to the

bearings for a longer period than would be permitted by the normal supply of oil at the conclusion of a run. Care should be taken, however, that the amount of oil introduced into the crankcase through the breather does not exceed the amount necessary to bring the oil tank supply up to its maximum capacity.

Carburetor Settings.—The Stromberg NAS-12 carburetors on the model 3A-2,500 engines are supplied with slightly different settings than used on former engines.

These settings are as follows:

Chokes—bore 3⅛"
Main jet size No. 36
Discharge nozzle
  Bore—3/32"
  Rose type head dia.—1 1/16"
  Air bleed hole—No. 47
Main discharge nozzle stud
  Main hole—¼" dia.
  Four upper holes—No. 48 drill
  Six lower holes—No. 42 drill

Accelerating well screw
  No. 10 drill—large hole
  No 52 drill—small hole
Idling tube assembly
  Jet size—No. 38 drill
Idling air bleed
  Drill size—No. 56
Idling discharge jet
  Drill size—No. 32

Valve Housing Covers—The model 3A-2,500 valve housing covers have been modified at the rear end to provide a wider flange and better gasket condition than obtained on the former engines. This change necessitates a similar change on the flange of the camshaft side drive gear housing.

Screw Tappet Adjustment.—Tappet clearances on the model 3A-2,500 engine are adjusted by threaded tappets instead of the shim adjustment previously used. The arrangement is similar to that described on page 36 as used on the model 2A-1,500 engine. In order to decrease the clearance, both the upper and lower nuts are turned to the right. To increase the clearance, the nuts are both turned to the left. It is of extreme importance that the lower nut be securely tightened after making an adjustment, and it is advisable to make a double check on this point. Standard tappet clearance on the 3A-2,500 engine is the same as in former engines, namely:

Inlet valve tappet clearance..........	.025 to .028
Exhaust valve tappet clearance........	.038 to .041

Crankcase Breathers.—One large breather is fitted to either side of the crankcase at the center crankcase support in place of the two breathers at either end of the crankcase formerly used. The new breathers are considerably higher, and this change was made to eliminate loss of oil through the breathers at high speeds and also to prevent interference with plane structure.

Oil Gauge Connections.—The connection for the oil pressure gauge on the 3A-2,500 engines consists of a two-bolt steel forging forming a hose connection and mounted on the rear wall of the crankcase. This connection registers with a passage communicating with the center camshaft drive-shaft upper bearing. In previous engines the oil gauge connection was taken off the front end of the main longitudinal pressure manifold and it was necessary to run a gauge line the entire length of the engine in order to secure a suitable connection at the rear end of the engine.

Crankshaft Oil Thrower.—A large diameter centrifugal type oil thrower has been substituted for the felt washer formerly used on the model 2A-2,500 direct-drive engines. This construction insures freedom from oil leakage at the front end of the crankcase and eliminates maintenance work in replacing worn felt washers.

Starting Jaw.—The crankshaft gear support has been changed to receive a slightly different form of starting jaw so as to permit installation of hand or electric starters of any of the well-known types with no change other than the starting jaw designed for that particular equipment. Previously an adapter casting had to be furnished on certain installations to mount certain types of starters.

Cooling Fins on Crankcase Lower Half.—On the model 3A-2,500 engine, cooling fins have been added to the under surface of the crankcase lower half or oil pan in order to assist in cooling the oil. It is considered advisable in airplane installations to insure a certain amount of air circulation over these surfaces. About ten square feet of cooling surface have been added in this fashion, and, assuming that the requisite air circulation is permitted over this cooling surface, it is permissible to reduce the external oil cooler from about 40 square feet to about 30 square feet of capacity on this account.

Camshaft Drive Center Gear Shims.—On previous engines shims have been used to obtain the correct backlash between the camshaft drive center gear and crankshaft gear. These shims have been placed between the camshaft drive center gear upper bearing and crankcase.

On the 3A-2,500 engine these shims have been removed and the correct backlash of the above mentioned gears is obtained by means of a correct thickness thrust washer which replaces the washer used on previous engines between the camshaft drive center gear and upper bearing.

On account of the limits in manufacture of the various parts, the thickness of this washer varies with different engines, and provision has been made for this by specifying several washers of varying thicknesses from which one can be selected for the correct backlash. After the correct washer has been selected the thickness of same is etched on the face of the washer, so that in rare cases of replacement the correct thickness washer can be drawn from stock.

Water Pump Shaft.—On some of the previous engines water found its way into the engine through the lower hole drilled in this shaft to provide lubrication at the bearing adjacent to the impeller, the oil for this lubrication coming from the upper bearing. Experience to date has proven that it is not essential that this bearing be lubricated in this manner and for this reason the lower hole has been removed which will prevent any possibility of water getting into the engine through this hole. The water pump shaft is provided with two bearings, both above the one referred to, which give it proper alignment, and the lower bearing being very close to the water pump packing, which has lubricating qualities, will receive lubrication from this source.

GENERAL SPECIFICATIONS

Model and Rating of Engine		
Model	2A-1500	2A-2500
Rating at 2000 r.p.m.		800 B.Hp.
Rating at 2100 r.p.m.	525 B.Hp.	
Rating at 2500 r.p.m.	600 B.Hp.	
General Form		
Bore	5 3/8"	6 3/8"
Stroke	5 1/2"	6 1/2"
Number of Cylinders	12	12
Total piston displacement	1530.4 cu. in.	2539.55 cu. in.
Rated r.p.m.	2100	2000
Cylinder arrangement	60 deg. Vee	60 deg. Vee
Cooling	Water	Water
Compression volume ratio	5.1:1 or 5.5:1 or 6:1	5.1:1 or 5.7:1
Crankshaft		
Firing order	1L-6R-5L-2R-3L-4R-6L-1R-2L-5R-4L-3R	
Overall length (direct and inverted)	53 3/4"	63 7/8"
Overall length (geared)	39 3/4"	46 13/32"
Journal diameter	3.00"	3.50"
Crankpin diameter	2.50"	3.25"
Number of bearings	7	7
Number of crank throws	6	6
	D & V 73 1/2 lbs.	D & V 135 lbs.
	G. 64 lbs.	G. 111 lbs.
Propeller Hub		
Type	Splined fit on crankshaft with split centering cones	
Dimensions:		
Outside diameter of flange	10"	12"
Width between flanges	5 3/4" to 7"	7 1/2" to 9"
Diameter hole in propeller	3 3/8"	4 3/8"
Bolt circle	8"	9"
Number of bolts	8	8
Size of bolts	1/2" dia.	5/8" dia.
Connecting Rods		
Length center to center	9"	11"
Type	Articulated	Articulated
Material	Chrome Vanadium Steel	
Gun Control Drive		
Type	Two Nelson type drives are provided	
Camshaft		
Length	38 3/8"	46"
Number	2	2
Diameter	1"	1 3/32"
Valve action	Cam followers arranged with vertical stem guide	
Pistons		
Material	Aluminum alloy	Aluminum alloy
Type	Slipper	Slipper
Wristpins		
Retaining device	Snap rings	Snap rings

	2A-1500	2A-2500
Cylinders		
Material	0.40 carbon steel	
Cylinder barrel, head and jacket	Steel individual assemblies. Valve port formed in aluminum valve housing extending over six cylinders.	
Valve Seats	2A-1500	2A-2500
Material	Steel	Steel
Form	Integral with Cylinder head	
Valves		
Number per cylinder	Four	Four
Form	Tulip Type	Tulip Type
Material	Inlet High Tungsten Steel. Exhaust Silchrome	
Seat angle	45°	45°
Lift of inlet valve	7/16"	1/2"
Lift of exhaust valve	3/8"	1/2"
Diameter of inlet valve port	1 15/16"	2 7/16"
Diameter of exhaust valve port	1 3/4"	2 1/16"
Valve Springs		
Type	Multiple Helical	Multiple Helical
Number per valve	7 piano wire springs arranged concentrically	10 piano wire springs arranged concentrically.
Valve Timing		
Inlet Opens	10° after top D.C.	10° after top D.C.
Inlet Closes	45° after bot. D.C.	45° after bot. D.C.
Exhaust Opens	48° before bot. D.C.	48° before bot. D.C.
Exhaust Closes	8° after top D.C.	8° after top D.C.
Camshaft Gear Train		
Type	See text	See text
Ignition		
Type	Two Delco battery ignition distributors at rear of engine driven from the camshaft drive side gear upper	
Alternatives	Two Model AG-12D Scintilla Magnetos mounted on bracket bolted to rear end of crankcase—driven by flexible couplings. Splitdorf or Scintilla Double Magneto mounted vertically in the Vee with separate distributor drives.	
Carburetor		
Vendor	Stromberg Motor Devices Co.	
Type	NA-Y6P	NA-S12
Number	2 duplex	2 single
Choke	1 15/16"	3 1/8"
Main Jets	40	36
Altitude control means	Back suction on float chamber	
Intake Manifolds		
Type	Exhaust Heated	
Crankcase		
Type	Box section type parted below the center line of the crankshaft. Special	Box section type parted below the centerline of the crankshaft. Main

	design incorporating through bolts parallel with cylinder axis.	bearings supported by caps.
Water Pump		
Type	Centrifugal	Centrifugal
Ratio of crankshaft speed to pump speed	1 to 1½	1 1/12
Gland type	Wrench adjusted stuffing box	
Driving train	Page	
Oil Pump	2A-1500	2A-2500
Type	Triple Gear	Triple Gear
Capacity at 1800 R.P.M.	2400 lbs per hour	2400 lbs. per hour
Fuel Pump		
Type	Wright Viking or U. S A S gear pump	U S A S. C-3 gear pump
Lubricating System		
Pressure	75 to 100 lbs. per sq. in.	
Type	Dry sump system with triple gear oil pump mounted in unit with screen in lower half crankcase, screen extending full length of oil pan to protect scavenging pumps	
Overall Dimensions		
Center to center of engine bearers	15¾"	18¼"
Overall length	65 7/16"	73 3/32"
Overall height	37¾"	42 7/16"
Overall width	26⅞"	30 13/16"
Weight of engines (dry)	With two Scintilla Magnetos with Delco 4½" Generator.	
Model 2A-1500 direct drive	*760 lbs.	*750 lbs.
Model 2A-1500 geared drive	880 lbs.	870 lbs.
Model 2A-1500 Inverted Drive	*780 lbs.	*770 lbs.
Model 2A-2500 Direct Drive	*1160 lbs.	*1150 lbs.
Model 2A-2500 Geared Drive	1380 lbs.	1370 lbs.

(*) No propeller hub.

The model 2A-1500 direct drive and inverted drive propeller hub assembly weighs 20 lbs. The model 2A-2500 direct drive propeller hub assembly weighs 36 lbs. 11½ oz.

STANDARD ADJUSTMENTS

	Model 2A-1500	Model 2A-2500
Inlet valve tappet clearance	.020"—.023"	.025"—.028"
Exhaust valve tappet clearance	.020"—.023"	.038"—.041"
Inlet valve opens	10° after top D.C.	
Inlet valve closes	45° after bottom D.C.	
Exhaust valve opens	48° before bottom D.C.	
Exhaust valve closes	8° after top D.C.	
*Minimum water outlet temperature	120° Fahr.	120° Fahr.
Maximum water outlet temperature	180° Fahr.	180° Fahr.
*Minimum oil inlet temperature	110° Fahr.	110° Fahr.
Maximum oil outlet temperature	200° Fahr.	200° Fahr.
Minimum oil pressure at 1000 r.p.m.	40 lbs.	40 lbs.
Minimum oil pressure at 2000 r.p.m.	50 lbs.	50 lbs.
Maximum oil pressure at 1000 r.p.m.	100 lbs.	100 lbs.
Maximum oil pressure at 2000 r.p.m.	100 lbs.	100 lbs.

STANDARD ADJUSTMENTS—Continued

Ign. full advance—5.5 1 comp ratio.	35 degrees	44 degrees
Ign. full advance—5.1 comp. ratio...	40 degrees	50 degrees
Magneto contacts should open.	.010"—.012"	010"—012"
Ignition distributor contacts should open .	.014"—016"	.014"—.016"
Sparkplug gap	.014"—.016"	.014"—016"

(*) For most satisfactory results.

VALVE SPRING LOADING

	Model 2A-1500	Model 2A-2500
Inlet valve spring assembly		
Valve open	82 6 lbs.	90 lbs.
Valve closed...	42 0 lbs.	48 lbs.
Exhaust valve spring assembly		
Valve open	76 8 lbs.	90 lbs.
Valve closed	42 0 lbs	48 lbs.

STANDARD CLEARANCES

		Model 2A-1500	Model 2A-2500
Piston skirt clearance in cylinder		016"—.017"	.021"—023"
Master rod bearing clearance on crankpin .	on dia	002"—004"	003"—.005"
	endwise	008"—020"	008"—020"
Link connecting rod bearing clearance	on dia	0005"—002"	.0005"—002"
	endwise	004"—008"	004"—008"
Main bearing clearance	on dia	0025"—0045"	0025"—0045"
	endwise	* 0625" nominal	* 0625"—nominal
Camshaft bearing clearance. . ..	on dia	0015"—0035"	.0015"—0035"
Camshaft drive center shaft upper bearing clearance...	on dia.	.0015"—0035"	.0015"—0035"
Camshaft drive center shaft lower bearing clearance	on dia.	0015"—0035"	0015"—0035"
	endwise	006"—010"	.006"—010"
Camshaft drive side gear upper bearing clearance..............	on dia	0015"—0035"	.0015"—0035"
	endwise	006"—010"	.006"—010"
Camshaft drive side gear lower bearing clearance	on dia	.0015"—0035"	0015"—0035"
	endwise	006"—010"	.006"—010"
Water pump gear bearing clearance	on dia	.0015"—.0035"	.0015"—0035"
	endwise	.006"—.010"	006"—010"
Piston ring gap		.02125" 04125"	.02125"—04125"
Up and down ring clearance			
Top ring...		003"—0035"	003"—0035"
Center ring...		.0025"—.003"	0025"—.003"
Lower ring....		.002"—.0025"	.002"—0025"

(*) Crankshaft on direct engines is located by propeller thrust bearing, shims being provided to locate the shaft correctly.

Unpacking.—Packard aircraft engines are shipped in substantial wooden boxes with suitable identification stenciled on the outside. One end of the box is fastened with wood screws, whereas the remaining sides are nailed and should not be disturbed. To remove the engine from the case the end cover fastened with wood screws should first be removed. Following this the ten lag screws (four on each side and two on the end) which fasten the "skid" on which the engine is mounted, to the inside of the case should

be removed. The skid with the engine attached can then be pulled out from the packing case.

The bolts holding the engine to the top sills of the skid should be removed after carefully unpacking the tool kit and other miscellaneous material shipped with each engine, and which should be checked off the packing slip. A substantial sling should be passed around the engine for hoisting purposes. If no starter is mounted at the rear end of the engine it is advisable to fasten a couple of pieces of flat stock under the two lower screws retaining the cover over the crankcase starter opening to prevent the rear bight of the sling from slipping off the crankcase when raising the engine. The forward bight of the sling can be passed under the nose of the engine of either the direct or geared type without fear of this end of the sling slipping off.

Inverted engines are shipped and handled in the same manner as direct engines, that is to say, with the cylinder banks upright; the only extra precaution necessary in handling the inverted engines is to guard against oil entering the electrical apparatus, which should be inspected and cleaned if necessary, after the engine has been inverted to its operating position.

Preparing Packard Engines for Service.—Assuming that an engine has been idle for a considerable period it is advisable to make a careful inspection as outlined below before attempting to start the engine. Remove all sparkplugs and insert a small quantity of oil in each cylinder. Turn the engine over by hand to insure spreading the oil over the cylinder bores. Clean the sparkplugs, or renew same if necessary, and check the sparkplug gaps to be about .015 inch.

Remove the valve housing covers and clean off traces of moisture or gummy oil and lubricate all moving parts generously with an oil can. Tighten down all cylinder to valve housing hold-down nuts. Special wrenches are furnished in the tool kit to fit these nut, there being 30 to each bank of six cylinders. These are arranged in three longitudinal rows, the inner and outer row of nuts seating in counterbores in the valve housing top surface and some of the center row of nuts serving to hold down the camshaft bearing pedestals. It is important that these nuts be drawn down firmly and with equal pressure. Check tappet clearance and adjust, if necessary, performing this work after tightening down the valve housing nuts as explained in the previous paragraph.

Replace the valve housing covers, being careful to locate the gasket in its correct place. It is advisable to remove the tachometer driver before replacing the camshaft cover in which this unit is mounted. After replacing the cover the adapter for the tachometer drive can be screwed home and a screwdriver should be used to ascertain that the driving shaft is free in its bearing and lined up correctly with the driving dog mounted on the end of the camshaft.

Ignition contacts should be examined and cleaned, if necessary. If magneto ignition is used the contacts should be adjusted to .010 inch to .012 inch gap and care should be taken to insure the contact surfaces being parallel and perfectly clean, free from oil. If generator ignition is used, the contacts should be set .012 inch to .014 inch. It should be noted that the magneto contacts are of platinum alloy and can be readily filed, but the

generator ignition contacts are of tungsten and can only be smoothed with a carborundum stone. The distributors should be examined for being clear and dry and the distributor rotor should be inspected for being tight on its shaft and the center carbon brush in the distributor should work freely.

The oil screen should be taken out and cleaned. All wiring and connections should be carefully examined for being tight and sound. The carburetor screens should be taken out and cleaned after removing the square head retaining plug on top of the carburetor. The carburetor throttles should be examined for being synchronized. It is more important that the throttles should close simultaneously rather than that they should both be strictly vertical when wide-open. However, there should be not much discrepancy in the wide-open position. Gasoline piping up to the carburetors should be checked for leaks, pumping up pressure by hand, if necessary. The water system should be carefully gone over for evidence of leaks, loose hose clamps, or rotted hose connections. In checking over a new installation every possible precaution should be used to insure freedom from air locks in the system, which can sometimes be located by "gurgling" sounds immediately after the system has been filled with water. Engine bearer hold-down bolts and propeller hub bolts should be carefully examined for being tight and safetied. Spark, throttle, mixture, radiator shutter, and gasoline shut-off controls should all be carefully examined for being free and properly safetied.

Starting the Engine.—Before starting a new engine or one which has stood idle for some length of time, it is advisable to inject a small quantity of lubricating oil (about ⅓ of a teaspoonful) through a sparkplug opening in each cylinder. With the ignition switches "off" crank the engine over a few times to distribute the oil over the cylinder walls. Be sure that the cooling system is full of water, all drain plugs securely closed and an ample supply of oil and gasoline in their respective tanks.

It is advisable, if possible, to secure a supply of hot oil and hot water for the engine to be poured in just before starting the engine in extremely cold weather. The hot water will serve to assist vaporization of the fuel and lower the viscosity of the oil on the cylinder walls so as to promote easy cranking. The hot oil will insure a ready flow of oil between the oil tank and the oil pumps and will prevent excessive pressure being generated due to congealed oil in the pipes and oil cooler. Under these extreme cold weather conditions it is preferable to prime each cylinder separately through a sparkplug opening with about ¼ teaspoonful of ether or a mixture of ether and high test gasoline. All twelve cylinders should be thus primed to insure a prompt start.

In moderately cold weather, with a cold engine about three or four operations of the primer should be sufficient to insure excess fuel for starting. Excessive use of the primer will result in washing the lubricating oil off the cylinder bores with consequent possible damage to the pistons and cylinders due to lack of lubrication. In warm weather or when the engine is warm it is advisable to use the primer sparingly, if at all, for once the engine becomes saturated with an over rich mixture of vaporized fuel it is extremely difficult to obtain a prompt start. Should the engine give a few intermittent explosions, expelling black smoke when starting up, it is a sur

sign of an excessively rich mixture. When an engine becomes "loaded" in this fashion and fails to start after repeated cranking, it is advisable to turn the engine over backwards by means of the propeller for four or five revolutions, thus permitting the drawing in of pure air through the exhaust ports and leaning down the excessively rich mixture in the cylinders. The engine should then start promptly after cranking ahead for two or three revolutions.

Starting with Magneto Ignition.—It is necessary to crank the engine at a rate of about 30 or 40 revolutions per minute in order to obtain a sufficient spark from the engine magneto to insure a prompt start. Therefore, when the engine is cranked over by the ordinary form of geared hand crank or an electric starter of the conventional type it is necessary to provide the auxiliary sparking means of the hand crank or "booster" magneto to compensate for the slow cranking speed. This magneto is connected to a "trailing" brush on the high tension distributor and this automatically insures safety in cranking by supplying a shower of sparks in a well-retarded position. Therefore, when cranking the engine over slowly in order to start, the booster magneto should be operated briskly, and when starting a cold engine it is advisable to continue operating the booster until the engine has picked up several hundred r.p.m.

When cranking the engine over, the magneto switch should be placed in the "both on" position and the spark control advanced about one-half way. The throttle should be barely cracked unless it is thought that the engine is loaded with a rich mixture, in which case better results will be obtained by opening the throttle a fraction of its travel. With starters of the "inertia" type it is generally possible to start the engine on the main magnetos without the use of the hand crank magneto. However, one of the latter instruments should be always available for emergencies.

Starting with Battery Ignition.—The engine must never be cranked by hand with the ignition switch "on" unless the starting crank is provided with an efficient anti-kick device. With the inertia type hand starter or any electric starter it is of course, necessary to have the ignition switch "on" with the spark control full retarded. In case it is necessary to start the engine regularly by means of the propeller, a battery buzzer coil or a hand crank magneto should be used to deliver a delayed spark to the trailing brush of the distributor and in this event the engine must always be started on "compression." That is to say, the engine should be turned over a few times with the switches "off" and then with everybody clear the buzzer or hand crank magneto should be operated, this procedure being repeated until the engine starts.

After the Engine Starts.—It is advisable to advance the spark at least half way as soon as the engine has fired a few times. Then, after a few seconds of idling the spark lever can be retarded in order to warm the engine up more quickly. As soon as the engine starts the oil pressure gauge should be carefully watched and the engine throttled to not over 500 or 600 r.p.m. until at least twenty pounds pressure is indicated on the gauge. Under no circumstances should an engine be run for more than 30 seconds without an indication of some oil pressure on the gauge. Failure to observe this precaution will almost invariably result in serious damage to the engine.

The engine should not be speeded up until at least 40 pounds pressure is indicated. The throttle may then be gradually opened and the spark advance may be set to give the maximum revolutions. When the water outlet temperature has reached about 120 degrees Fahrenheit or 50 degrees Centigrade, the throttle may be opened up wide to check the functioning of the engine on the ground under these conditions. The r.p.m. obtained will, of course, depend upon the propeller characteristics and may vary from 1,500 r.p.m. to 1,800 r.p.m., depending upon the requirements.

If the engine fails to come up to the desired r.p.m. and is more than 50 r.p.m. lower than is expected the plane should not be flown until the cause has been determined. While running with the throttle wide-open the individual ignition switches should be tried and the engine should function equally well on single ignition either right or left with possibly the loss of 25 or 50 r.p.m. as compared with operation on "both" ignition. The engine should not be run with wide-open throttle on single ignition any longer than necessary to determine that each ignition system is functioning. Running the engine wide-open on single ignition promotes detonation and is therefore injurious to sparkplugs and valves. The throttle should be held wide-open only long enough to insure that everything is functioning properly and in the case of a new plane it is advisable to continue this operation until the water outlet temperature has reached 180 degrees Fahrenheit so as to guard against a steam trap being formed at the higher temperature in the water system. Evidence of a steam trap or faulty circulation is shown by the water outlet thermometer rising very rapidly whereas the water inlet thermometer rises slowly.

The "oil out" thermometer should also be carefully watched and this thermometer should at no time indicate an oil temperature of more than twenty degrees Fahrenheit or eleven degrees Centigrade, higher than the water outlet thermometer reading. It is, of course, important that both water and oil thermometers register about the same reading after the plane has stood idle for a considerable length of time. While the engine is operating at full throttle it is advisable to check all controls, the spark, throttle, mixture and radiator shutter controls to observe that these work with perfect freedom under approximately flying conditions. Should it be found necessary, especially on a hot day, to run the engine for a considerable period of time on the ground, thus heating up the oil and water to an excessive degree, the engine should be throttled to about 500 to 600 r.p.m. in order to cool down the water and oil before taking-off. Under these conditions the water outlet temperature should be between 120 and 140 degrees Fahrenheit, or between 50 and 60 degrees Centigrade.

Stopping the Engine.—Except in emergency it is always advisable to stop the engine by closing the throttle gradually, shutting off the gasoline supply and allowing the engine to continue to run until the carburetors become drained. Then, just as the engine is about to stop firing, the throttle should be quickly opened wide and the ignition switches turned off.

Care of Models 2A-1,500 and 2A-2,500 Aircraft Engines.—After each flight the engine should be given a general surface inspection and prepared for immediate flight. General surface inspection is meant to be construed

as careful inspection of propeller hub lock nuts, propeller hub bolts, engine hold-down bolts, cylinder hold-down nuts, hose connections, ignition wiring, and spark and gas control linkage. The sparkplugs need not be removed unless previous operation indicated trouble in this connection, but it is advisable to check all plugs for being tight in the cylinders. During cold weather the water should be drained from the engine, by removing the plug at the bottom of the water pump inlet connection; if the engine is to be idle long enough to freeze, unless proper anti-freeze solutions are used.

After Every Twenty Hours of Engine Operation.—Following every twenty hours of engine operation a very complete inspection should be made; this inspection should include the daily inspection routine and the following additions: Clean oil and gasoline strainers. On the model 2A-1,500 engine the oil screen is located on the suction side of the pressure pump. On the model 2A-2,500 engine there are two oil screens to be removed and thoroughly cleaned; one of these screens is located on the suction side of the pressure pump, as in the model 2A-1,500 engine, and the other is mounted in a compartment in the crankcase lower half on the pressure side of the pressure pump. The gasoline strainers are located at the gasoline inlet connection and can be taken out after removing the square head retaining plug on top of the carburetor. Drain oil from lubricating system and refill with fresh oil.

Inspect magneto breakers or distributor interrupters and adjust if necessary. Check tappet clearance and adjust any that vary more than .004 inch from the specified limits. Check compression. Tighten cylinder head to valve housing nuts and cylinder to crankcase nuts. On geared engines inspect and tighten, if necessary, the bolts holding the reduction gear case to the crankcase. Remove sparkplugs—clean and adjust gaps where necessary. Remove plugs from exhaust-heated intake manifolds and clean out exhaust passages. Drain and put in fresh water, being sure that the system is completely full and free from air locks. After 200 hours of engine operation a complete overhaul is recommended.

To Check Timing Without Disassembling.—In order to determine whether the engine is correctly timed without disassembling to verify gear relationships, a marked sector is provided integral with the rear camshaft bearing cap on each bank of cylinders. This sector bears three lines corresponding to two events in the cycle of cylinder No. 1 and one event in the cycle of cylinder No. 6. The timing of each bank is checked separately by its individual sector. The valve housing cover is removed and the engine rotated to bring the mark on the circumference of the camshaft gear in line with that on the timing sector marked "top dead center cyl. No. 1." The position of the piston in cylinder No. 1 may then be checked in this respect and the engine rotated to bring the camshaft gear marking opposite the line marked "Exhaust close, Inlet open Cylinder No. 1" on the timing sector.

The piston of cylinder No. 1 should now be at the neutral point, that is, the exhaust valve having just closed and the inlet valve about to open, and the positions of the valves and camshaft for this cylinder may be checked. The engine is then rotated counter-clockwise to bring the cam-

shaft gear marking opposite the third line on the timing sector marked "spark full advance cyl. No. 6" and the position of the distributor rotor and breaker points can be observed to verify the correctness of the ignition timing for this cylinder. With these three events of the cycle checked for both banks of cylinders, the engine may be considered properly timed.

Grinding Valves Without Disassembling Cylinder Blocks. Care of Valves.—The running time of aircraft engines between overhauls is largely a matter of the necessity for grinding valves, especially the exhaust valves, and it therefore pays, in order to insure long periods between overhauls, to watch the valve condition carefully and carry on such maintenance work as outlined below whenever conditions require this work to be performed. A sure check on the condition of the valves can be obtained by measuring and recording the tappet clearances, particularly the clearances of the exhaust valve tappets. This inspection can be carried out by two men in about an hour and should be done at regular intervals, say every twenty hours of engine operation. A feeler gauge is inserted between the cam followers and the cam and whenever this clearance shows signs of closing up it is advisable to proceed further and ascertain the reason therefor. The clearances for the model 2A-1,500 and 2A-2,500 valves are given below:

Model 2A-1500 inlet valves............	.018" to .021"
Model 2A-1500 exhaust valves....	018" to .021"
Model 2A-2500 inlet valves..............	.025" to 028"
Model 2A-2500 exhaust valves........	.038" to .041"

In case any of the clearances show a marked decrease the compression on that particular cylinder should be checked. A simple and sufficiently accurate method of checking the compression on these engines is to remove all the outside sparkplugs and check each cylinder in turn following the firing order on each block of 1-5-3-6-2-4, the propeller being turned slowly until the inlet valve on each of these cylinders is closing and then being turned briskly for somewhat less than one-half revolution, the outside sparkplug opening being closed by holding one thumb over the opening. In this manner the compression in each cylinder should hold for several seconds, being released finally by removing thumb from the sparkplug opening. In case any valves are "blowing" it is very simple to determine it in this fashion, and assuming that only one or two valves in the engine need attention it is advisable to grind the valves in without removing the cylinder blocks in the manner outlined below. In recommending this procedure, however, it should be borne in mind that the utmost care should be used in following the instructions and this should be entrusted to skilled and experienced mechanics only.

Grinding Valves Without Removing Cylinder Blocks.—Having determined, as outlined above, which particular valve needs grinding the cam shaft should be first removed, taking care to identify the position of the camshaft with relation to the crankshaft, it being desirable to have the "o's" on the camshaft gears correspond for this operation. After removing the camshaft disassemble the valve springs and upper collar from the valve to be ground, but do not remove the safety ring which prevents the valve from dropping into the cylinder after the spring retainers have been removed. Now secure a clean length of about ten feet of one-half inch diam

eter rope to be fed in through the sparkplug opening opposite to the valve which is to be ground in and insert sufficient of the rope in the cylinder to catch any particles of valve grinding compound which may subsequently be dropped off the valve seat. Needless to say, the free end of the rope should be kept in the clear in order to remove same later. The grinding compound can be applied to the seat of the valve by allowing the valve to drop as far as the safety ring will permit and applying a small portion of valve grinding compound on the end of a screwdriver introduced through the near sparkplug opening. Great care should be used in only applying a sufficient amount of compound for the operation.

The valve is ground in by means of a suitable tool clamped to the end of the valve stem and the necessary pressure can be applied either by pulling up on this tool or preferably by a simple forked lever used as a pry under the tool. Sketches of suitable tools will be supplied upon application by the engine makers. The compound can best be cleaned off the valve seat by inserting a rag through the sparkplug opening and catching same between the valve seat and the cylinder, rotating the valve with the rag interposed and removing the rag and rotating the valve against its seat. Repeat this operation until all the compound has been removed, as can be detected by the smooth seating of the valve on its seat. When it is believed that a good seat has been obtained the rope should be removed, the sparkplug inserted on the inlet side, and the compression tested by rocking the engine, using the thumb to close the outer sparkplug opening. If the valve continues to "blow" the grinding operation should be resumed and continued until such time as a tight seat is obtained. In rocking the engine care should be used not to lose sight of the position from which it was moved as the crankshaft must later be restored to its first position in order to avoid losing the correct timing adjustment. Unless a valve has been neglected for too long a time it should be possible to perform the operations outlined above in about three hours with two men, which represents a great saving of time as compared with removing the cylinder block. The success of the operation depends altogether upon preventing any valve grinding compound dropping on the pistons or the cylinder walls, and this can be avoided by packing the cylinder with plenty of rope and using the valve grinding compound very sparingly.

Summary of Operations for Complete Tear-Down of Models 2A-1,500 and 2A-2,500 Aircraft Engines.—1. Remove carburetors and cross headers. On both the model 2A-1,500 and 2A-2,500 engines the carburetors can be lifted out as an assembly with the cross manifolds as shown in the photograph in Fig. 703 B, it being first necessary to remove all sparkplugs. 2. Remove valve housing covers, first unscrewing the tachometer drive adapter. When replacing the valve housing cover the tachometer adapter should be screwed in place last, taking care that the tank on the tachometer driving shaft engages the slot in the camshaft gear flange. 3. Remove camshafts, holding the camshafts in place by special "C" clamps until all camshaft bearing cap nuts have been taken of and then back off evenly on both C clamps to avoid springing the camshafts. 4. Remove camshaft side drive gear upper after taking nuts off flanged bearings. (Keep shims with bearing by wiring them together.) 5. With geared engines remove reduc-

tion gear next. 6. Loosen hose clamps on valve housing oil drain tubes a the front end and side drive housings at rear end and remove drain tube at front end. Disconnect crankcase to valve housing oil feed lines at rear end of engine. 7. Loosen hose clamps on cylinder water inlets and remove cylinder water inlet manifold after loosening lower hose clamp at water pump outlet. 8. Remove ignition cable tube assemblies. 9. Remove the cylinder to crankcase nuts, using the special wrenches furnished with both the model 2A-1,500 and 2A-2,500 engines. 10. Roll the engine over 30 degrees until the cylinder block on one side is in a vertical position.

11. Lift cylinder block assembly by means of a sling passed under notched wooden blocks placed under each end of the valve housing. Great care should be used not to cramp the pistons by raising one end of the block higher than the other. The crankcase center studs should be protected with rubber hose before lifting the cylinder block assembly completely so as to prevent the pistons from falling onto these studs as they are released from the cylinder bores.

12. Roll the engine over 60 degrees to bring the other bank of cylinders in a vertical position and remove this cylinder block in the same manner

13. Remove the camshaft side gear lower assemblies and magneto or generator support, keeping each set of shims with its own assembly.

14. Remove camshaft center drive gear assembly after taking out the cap screw projecting through the rear end of the crankcase which holds the lower bearing in position (preserve shims in their proper position).

15. Remove pistons by driving out piston pins with a special drift after taking out the retaining snap rings. It will be noted that the pistons are marked with their respective numbers on the rear cross rib and care should be used in assembling in the same fashion. Warming the pistons up slightly will greatly facilitate removing the piston pins and this can be accomplished by applying cloths soaked in hot water to the pistons When re-assembling the pistons on the connecting rods the pistons can be immersed in a pail of hot water, after which it will be found the piston pins can be slipped in place merely by hand pressure.

16. Roll the crankcase over bottom side up and remove the pump unit bodily.

17. Remove the crankcase lower half or oil pan.

18. Remove main bearing caps, taking special note if all main bearing studs or bolts are snug in the crankcase. Note that the bearing shells are numbered on the rear or timing gear end of each bearing. Also note that the bearing shells carrying the oil grooves are located in the crankcase upper half, the half shells resting in the bearing caps having no oil grooves in the bearings.

19. Remove bolt from starting jaw. The starter jaw is provided with ½-twenty thread tapped hole and the puller body, supporting the head of a ½-inch cap screw, should engage the rear face of the crankcase and in this manner the jaw should be pulled off the crankshaft.

20. Lift out crankshaft complete with connecting rods by means of chain falls and suitable slings to avoid damage to the shaft. Support crankshaft from bench rigidly by bolting one end in a vise between two pieces of wood or soft jaws and supporting the other end from the floor by means of a suitable timber.

21. Remove connecting rods individually from the crankshaft, paying special attention to keeping mating parts together. It should be noted that both bearings and connecting rods are numbered toward the rear of the engine and great care should be exercised when re-assembling to get them in their proper locations. It is very important that the master connecting rods be fitted to the right bank of cylinders, the link rods being on the left when facing the anti-propeller end of the engine.

Re-assembling the Model 2A-1,500 and 2A-2,500 Aircraft Engines.—In general the work of re-assembling the engine consists in following the above operations in reverse sequence. However, inspections are necessary at frequent intervals to ascertain that the gaskets are in good condition and correctly located, timing gears have the correct backlash, and all bearings have their diametrical and end clearance in accordance with the limits outlined under heading "Standard Clearances." It is extremely important that all oil passages throughout the engine be scrupulously clean and this should be determined by repeated flushing operations followed by blowing out with compressed air.

Crankshaft Plug Assembly.—The crankshaft plugs in the crankpin journals should be removed and the inside of the crankpins thoroughly cleansed during overhauling operations. Perfect cleanliness is essential and no waste or rags liable to deposit lint should be used in cleaning the parts of the engine, and all bearings should be liberally lubricated with an oil can when re-assembling.

In replacing the piston pin snap rings it is very important that these rings should have the proper tension and fit snugly in the groove provided in the piston boss. Any snap rings which can be easily turned after having been sprung into the groove should be rejected.

When lowering the cylinder blocks in position over the pistons it will be found advisable to have No. 1 and No. 6 pistons on top center. The piston ring slots should preferably be arranged so that the top ring slot points toward the front of the engine, the bottom ring slot towards the rear, and the middle ring slot towards the center. With the rings arranged in this fashion it is possible to lower the cylinders over the rings without the use of a ring clamp, although it is highly desirable to make up a set of such clamps using about one inch by $\frac{1}{16}$ inch sheet brass.

It is advisable to repack the two stuffing boxes provided on the water pump, using for this purpose nonmetallic moulded packing as furnished by the engine manufacturer. The ignition wires should be carefully tested and inspected and if the rubber insulation has deteriorated to any extent at all the wires should be replaced. It is similarly advisable to replace all hose connections and this is especially true of gasoline hose connections.

In re-assembling the engine a great deal of care should be taken in following the markings of the various parts identifying their location. When installing such parts as main bearings, main bearing caps, connecting rods, pistons, etc., where the question arises which way the part should face when installed, it should be borne in mind that all such parts are numbered on those faces nearest to the rear or timing gear end of the engine.

The cam followers, however, have numbers etched on their flat surfaces away from the rubbing surface on the camshaft bearing. Valves have their

numbers etched on the upper end of their stems. The valve springs and upper spring collars can be interchangeably used on all valves. The valve spring guide assemblies, however, have upright guides for the inlet valve springs, and spirally arranged guides for the exhaust valves to rotate during operation.

Removal of Cylinders from Valve Housing.—When overhauling the engine it is not necessary to remove the cylinders from the valve housing unless water leaks develop or either cylinders, valve housing or gasket require replacement. In this event, in re-assembling the cylinders to the valve housing it may be necessary to give the gasket a very light coating of white lead. Care must be exercised in tightening up the nuts gradually so as not to bind the doweled portion of the stud.

After assembling cylinders to valve housing with camshaft bearings and both valve housing end castings in place the assembly should be tested for water leaks. This can be accomplished by introducing water at one of the cylinder water inlets after plugging the rest. Allow water to fill the cylinders and valve housing until overflowing out of the valve housing water outlet, then plug outlet. This method is necessary to prevent any air remaining in the assembly, thereby giving a false test result. With all outlets plugged the assembly should stand 30 pounds water pressure at water inlet without leaks.

In assembling the cylinders to the valve housing it will be noted that there are two different types of cylinders depending upon the relationship between the water inlet pipe and the inlet and exhaust ports respectively. One type of cylinder is used on cylinders Nos. 1, 3, 5 on the right bank and Nos. 2, 4, 6 on the left bank, this type of cylinder having the water inlet on the exhaust port side. The other type, having the water inlet on the inlet port side of the cylinder, is used on cylinders Nos. 2, 4, 6 on the right bank and Nos. 1, 3, 5 on the left bank. In ordering replacement cylinders it is necessary to specify the exact cylinder required, as "No. 3 right," "No. 4 left," etc. No. 1 right and No. 1 left being the cylinders at the timing gear end.

Tappet Adjustment.—With this arrangement of valves, cam followers and camshaft, it is necessary to synchronize the tappets on the same cam follower within .003 inch. On the Model 2A-1,500 engine the tappet clearance is adjusted by manipulating the upper and lower nuts on the tappet stud. To decrease clearance both of these nuts are turned to the right; to increase the clearance both of these nuts are turned to the left. After securing the desired adjustment, the two nuts should be securely locked against each other and the lock stamping engaged in either of the two slots in the cam follower which will place the stamping opposite a flat on the lower nut. The upper nut is locked by a cotter pin in the usual fashion. It is very important that the upper nut be drawn very tight before inserting the cotter pin.

On the Model 2A-2,500 Engine.—After determining the correct shim thickness, if same is less than .015 inch, it should consist of one shim and if more than .015 inch it may consist of two. The following shim thicknesses are available, .005 inch, .008 inch, .016 inch, .018 inch, .021 inch, .02[illegible] inch, .030 inch, .032 inch, .034 inch, .036 inch, .038 inch, .040 inch, .042 inch,

and it is exceptional when any dressing of shims is necessary. After the tappets have been finally assembled, the nuts should be securely locked in place with cotter pins.

Valve Grinding.—When overhauling the engine after removing the cylinder block and before removing the valves they should be tested for gas tightness. This can be accomplished by first removing the camshaft and cam followers, insuring seating of the valves by pounding lightly on the end of the valve stem. Then place the block on its side with the open ends of the cylinder propped up sufficiently to allow pouring gasoline into the inlet and exhaust ports in succession. Any of the valves which show the slightest seepage of gasoline through the ports into the cylinder barrel after standing a few minutes should be removed and reground. Both the inlet and exhaust valves are identified by etched numbers at the upper end of the stem. These numbers run from one to twelve for both right and left hand banks and for both inlet and exhaust valves, these being of different design and not interchangeable, thus not requiring a different marking system. All valves are marked starting from the timing gear end, No. 1 valve being the outboard valve either inlet or exhaust or right or left. "R" or "L" indicates whether the valve belongs to the right bank or left bank; the odd-numbered valves being all located outboard; and the even-numbered valves being all located inboard. To assist further in identifying the valves the valve housings are stamped with the valve numbers on the upper face and immediately adjacent to the base of the valve springs.

To remove the valve it is necessary to hold the valve up against its seat from the inside of the cylinder and depress the valve spring upper collar after which the keys can be removed. This will enable removing the spring assemblies. After removing the valve springs the valve lock ring just below the valve key rings can be pried out of position and the valve will then drop into the cylinder. In case the valve seats in the cylinder are pitted, they should be reseated with a reaming tool and any valves which show pitting on their seats should be trued up in a lathe or valve head grinder in the usual manner. It is very important when grinding the valves in to have the cylinder blocks placed in an inverted position with the valve stems hanging down so that the weight of the valve grinding tool will hold the valve on its seat. (See instructions in chapter on Liberty engines.) It is very undesirable to grind the valves in with the block resting on the bench and the valve stems horizontal as the tendency is to grind the valves in with the valve stems cramped in their guides. The valves should be ground in the regular manner until both the valve and the seat show a good frost-like appearance. The valve stems should be smoothed down with a stone or crocus cloth, if necessary. Whenever the exhaust valves have been removed they should be tested to determine whether the oil circulation is open. This can be accomplished by using compressed air introduced through the hole in the end of the valve stem and this should force a small quantity of oil out of the two small holes at the side of the valve near the top. As spare cylinders are shipped with some stock to be removed on the valve seat, after assemblying the cylinders to the valve housing, it is necessary to use a reaming tool piloted in the valve stem guide to establish the seat preparatory to grinding.

Camshaft Timing Instructions.—The following notes are to be followed in the event of re-assembling the engine or in the replacement of any of the parts affecting the camshaft timing. The standard crankshaft position for timing the engine is with No. 1 and No. 6 left pistons at the neutral point. All gear markings are in line or meshing in this position of the crankshaft and on fore and aft lines. The starting point is to turn the crankshaft to the neutral point for cylinders No. 1 and No. 6. ("Left hand" refers to the engine when viewed from the rear or magneto end when looking forward toward the propeller.) With the crankshaft set in this position it is now possible to assemble the gears correctly in the following order: Place the crankshaft gear on the crankshaft with the "O" on the crankshaft gear in line with the "O" on the crankshaft splined extension. Assemble the camshaft drive center gear as follows: On the model 2A-1,500 engine assemble the camshaft drive center gear with the two "O's" on the lower gear meshing with the "O" on the crankshaft gear. On the model 2A-2,500 engine the "O" on the crankshaft gear comes at a tooth space and is lined up with a single "O" on the engaging tooth of the camshaft drive center gear. It is very important that this gear be assembled in this position due to the fact that the double magneto (when used) is driven off its upper end

Rotate camshaft drive side lower gears in bearings so that "O's" on the upper end of the gears are to the rear and in a fore and aft line and assemble in the case in this position. Assemble the camshaft drive side gear uppers as follows: On the model 2A-1,500 engine assemble the camshaft drive side gear upper with the tooth space enclosed by two "O's" in line with the centerline of the shaft and to the front side. On the model 2A-2,500 engine assemble with the tooth mark "O" on the gear in line with the centerline of the shaft and on the front side. The camshaft drive side gear upper units are marked "R" and "L" to designate "right" and "left." To obtain the correct alignment when assembling these gears it may be necessary to loosen the nuts holding the cylinder flanges to the crankcase, thereby permitting the shifting of the cylinder block to the correct position. When the gear is in correct alignment it should be possible to feel the backlash in the lower gears by taking hold of the upper end of the gear and moving it radially. When the final position has been determined the cylinder hold-down nuts should again be tightened. If camshaft gear has been removed from shaft, assemble gear to shaft (both being marked "R" or "L") with "O" on gear teeth astraddle "O" "L" or "O" "R" on camshaft flange.

After the camshaft gear has been bolted to the shaft the assembly can be placed in the correct position as follows: On the model 2A-1,500 engine place the assembly in the bearings in such a position that the "O's" on the camshaft drive side gear upper mesh with the "O" on the camshaft gear. On the model 2,500 engine the two "O's" are on the camshaft gear and should mesh with the single "O" on the camshaft drive side gear upper. On the model 2A-2,500 engine attention is called to the fact that the markings on the camshaft drive side gear upper and camshaft gear do not line up every revolution of the camshaft drive side gear upper due to the odd speed ratio of these two shafts. For this reason unless it is definitely known that the crankshaft is in neutral position for No. 6 left cylinder it is possible

to assemble the gear with the markings meshing and be out of time. If the crankshaft position is not known the correct camshaft position can be checked by the fact that the marking on both camshaft drive side gear uppers should line up with the marks on both camshaft gears. This condition does not exist on the model 2A-1,500 engine and if the camshaft drive side gear upper has not been removed it is only necessary to rotate the crankshaft to a position which brings the tooth space enclosed by two "O's" in line with the centerline of the shaft and to the front side before assembling the camshaft gear.

If it is necessary to install a new camshaft gear the correct relationship with camshaft must be determined and the timing mark added. This is necessary due to the vernier adjustment provided between gear and camshaft to allow setting camshaft as close as possible to the correct position. The procedure in this event is to follow the above instructions up to the point of assembling the camshaft, after which proceed as follows: Assemble left camshaft with gear loose on shaft and rotate shaft until "O" designated "L" on flange is down and exactly in line with center of camshaft drive side gear upper. This is the correct position of camshaft for crankshaft. By trial determine position of gear requiring least movement of camshaft, if any, to mesh with previously located camshaft drive side gear upper with holes in gear and shaft in line. With vernier adjustment supplied the maximum error need not exceed two degrees on crankshaft.

After gear position has been determined and bolted to the camshaft etch letter "O" on camshaft gear tooth either side of tooth marked "O" on meshing gear. Also etch letter "L" on gear flange to distinguish "R" from "L." Follow same method for assembling right hand camshaft gear with crankshaft in same position. However, before marking gear check by rotating crankshaft 60 degrees in direction of rotation to neutral point for right block. If correct, rotate back to neutral point for left block and mark "O" and "R" on the gear.

Distributor Timing (Battery Ignition).—The standard crankshaft position for timing the distributor is with No. 1-L cylinder in firing position with full advance spark. The full advance spark setting for low compression pistons on the model 2A-1,500 engine is 40 degrees, and on the model 2A-2,500 engine the full advance spark setting is 50 degrees. For high compression pistons the full advance spark setting is 35 degrees on the model 2A-1,500 engine and 44 degrees on the model 2A-2,500 engine. With the crankshaft in this position the left distributor assembly including the gear is ready to be assembled. Before assembling, the upper half of the distributor body should be turned with reference to the lower half counter-clockwise, which is opposite the direction of rotation of the distributor.

Next, with the distributor in this position, turn the rotor so that the rotor finger lines up with the forward distributor head hold-down clamp, and distributor head dowel which is the correct distributor relationship for firing No. 1 left cylinder fully advanced. With the distributor parts in this relationship, lower the assembly into the housing with the low tension terminal to the front and the red line scribed on the inner hold-down slot on the distributor body lining up with the mark on the housing flange boss. This is approximate and the screws for holding the distributor down should

not be tightened until the breaking of the contacts is checked with whatever means are available, for full advance position by rotating the lower half of distributor, slots being provided for this purpose.

The assembly for this right distributor is exactly the same with the exception that the mark on the distributor hold-down flange should line up with the mark on the housing outer boss. After the breaker in the right distributor has been synchronized with the breaker in the left distributor and with both distributors in the full advance position against the stop, assemble the spark advance connecting rod. This connecting rod must be adjusted to a length which will maintain the synchronization obtained previously. After the rod has been assembled place the distributors in the advance position by rotating the left distributor by means of the connection that carries the control back to the cockpit and finally check the breaker in each distributor for synchronization.

Due to the fact that the marks on both the distributor and camshaft drive side gear upper housing are added on the original assembly of the engine it is necessary when new parts are used to add these marks after the correct timing position has been determined. The procedure for determining these marks is as follows: With the gear assembled to the left distributor rotate the upper half of the distributor relative to the lower flange portion counter-clockwise against the stop, also turning the rotor to line up with the front distributor head hold-down clamp. In this position assemble the unit to the housing with the low tension terminal forward, still keeping the same relative position of the parts.

After the distributor has been assembled, rotate the lower flange to obtain the correct spark advance on No. 1 left cylinder and after this is done scribe a line on both the distributor and housing boss for future use in re-assembling the engine. These marks should be about 1/32 inch deep and filled with red lead. The same procedure should be followed for the right distributor except that the line should be scribed on the outside boss.

Additional Tools—Not Furnished

Recommended Equipment for Base Repair Shops

Camshaft Removal Clamp.—Two of these tools are required to hold the camshaft down in its bearings while the nuts are being removed from the caps.

Valve Reseating Tools.—These tools are necessary as the service cylinders do not have the valve seat machined in them, this operation being done after the cylinder is bolted to the valve housing.

Camshaft Bearing Reaming Bar.—In assembling new bearings to the valve housing it is necessary to line ream these as the bearings furnished as spares are undersize.

Main Bearing Reamers.—Either a reaming bar carrying individual Martell reamers for each bearing or a scraping mandel should be provided for use when new bearings are installed. With the use of Martell reamers adjusted with great care to the proper dimensions it is not necessary to do any scraping.

Valve Guide Reamers.—These are necessary in case either new inlet

TOOLS FURNISHED IN TOOL KIT WITH ENGINE

Model 2A-1500 Engine

Center Punch
Cold Chisel
Hammer
Pliers
Punch
Screw Driver 3" Blade
Screw Driver 6" Blade
Thickness Gauge
Monkey Wrench
15° Double End Wrench
  ¼" and 5/16" opening
15° Double End Wrench
  7/16" and ½" openings
15° Double End Wrench
  ¾" and ⅝" openings
15° Double End Wrench
  15/16" and 1" openings
Spark Plug Wrench
Cylinder Hold-Down Nut Box Wrench
Cylinder Hold-Down Nut Socket Wrench
Handle for Socket Wrench ½ x 11
Double End Socket Wrench L-shap ¼"
Double End Socket Wrench L-shape 5/16"
Double End Socket Wrench L-shape ⅜"
Socket Wrench 5/16" Nut
Valve Housing Oil Inlet Connection Wrench
Valve Spring Compressor
Water Pump Impeller Puller
Water Pump Impeller Puller Screw
Tappet Adjusting Wrench (5/16")
Tappet Adjusting Wrench (⅜")
Propeller Hub Wrench for Direct Engines

Model 2A-2500 Engine

Center Punch
Cold Chisel
Hammer
Pliers
Punch
Screwdriver 3" Blade
Screwdriver 6" Blade
Thickness Gauge
Monkey Wrench
15° Double End Wrench
  ¼" and 5/16" opening
15° Double End Wrench
  7/16" and ½" openings
15° Double End Wrench
  ¾" and ⅞" openings
Sparkplug Wrench
Cylinder Hold-Down Nut Box Wrench
Cylinder Hold-Down Nut Socket Wrench
Handle for Socket Wrench ½ x 11
Double End Socket Wrench L-shape ¼"
Double End Socket Wrench L-shape 5/16"
Double End Socket Wrench L-shape ⅜"
Socket Wrench ⅜" Nut
Valve Housing Oil Inlet Connection Wrench
Valve Spring Compressor
Water Pump Impeller Puller
Water Pump Impeller Puller Screw
Tappet Adjusting Wrench (5/16")
Tappet Adjusting Wrench (⅜")
Propeller Hub Wrench for Direct Engines

or new exhaust guides are assembled to the valve housing, sufficient stock being left for reaming to the final size after being pressed in place. "Go" and "no-go" gauges should also be provided.

Camshaft Drive Side Gear Upper Bearing Reamer.—It is necessary to provide this reamer as this service bearing is undersize and the reamer is piloted from the lower bearing and therefore gives alignment between the upper and lower bearings.

Valve Grinding Universal Joint.—A universal joint is quite necessary due to the valve stems being rather close to the camshaft bearings. One end of this universal joint is attached to the valve and the other to a breast drill.

Water Pump Shaft Aligning Bar.—When a new water pump housing is installed it is necessary to align the water pump shaft bearings with the driving gear bearing (which is formed integral with the rear main bearing cap) by means of an aligning bar fitting into the two bearings. After locating the water pump in this fashion the dowel holes are drilled in the crankcase upper half, these dowels definitely locating the water pump in correct alignment for future assembly and disassembly.

Starting Jaw Puller.—The starting jaw is provided with a ½-in. twenty-thread tapped hole and the puller body, supporting the head the ½-inch cap screw, should engage the rear face of the crankcase.

Piston Pin Driver.—This drift is required to remove the piston pin from the piston following removal of the snap ring retainers.

Top Dead Center Gauge.—This gauge is screwed into a sparkplug opening and by a dial indicator determines the top dead center position of the piston.

Reduction Gears.—Special gear end bearing pullers.

Standard Types of Models 2A-1,500 and 2A-2,500 Engines

Direct Engines.—Both the models 2A-1,500 and 2A-2,500 engines are built in direct drive form suitable for "tractor" or "pusher" installation The direction of rotation of these engines is standard, that is to say, counter-clockwise facing the propeller end, thus requiring a standard right hand propeller for a tractor installation.

Geared Engines.—Both the models 2A-1,500 and 2A-2,500 engines are built with a self-contained gear reduction manufactured by the Allison Engineering Company, Indianapolis, and these units give the following gear reductions:

	Model 2A-1500	Model 2A-2500
R P M of engine	2000	2000
R. P. M. of propeller.......	1015	1012

In these geared engines the crankshaft turns in the standard direction and as these are simple spur gear reductions the propeller turns in the opposite direction, that is to say, in a clockwise direction facing the propeller, thus requiring a left-hand propeller for a tractor installation. These gear reduction units can be bodily removed from the engine by taking off the nuts and cap screws at the front end of the engine where the gear reduction is bolted to the vertical finished face of the crankcase. The crankcase is special for the geared engine and is not interchangeable with the direct drive crankcase owing to this flange construction

The reduction gear is accurately lined up with the crankshaft by means of two dowels as well as in the case of the model 2A-2,500 engine a pilot formed on the rear face of the reduction gear housing, and great care should be used in assembling and disassembling at this point to insure that the dowels are not loosened or damaged. A $\frac{1}{64}$-inch Vellumoid gasket is used between the crankcase and the reduction gear and care should also be used not to damage this gasket in re-assembling. The crankshaft on the geared engines is furnished with an integral flange at the driving end and a driving member with specially formed teeth is bolted to this flange. The "hair-pin" driving springs of the Allison flexible coupling engage these teeth, the purpose of the flexible coupling being to prevent impact loading of the gear reduction being transmitted from the crankshaft to the gear reduction. On the geared engines the crankshaft is located by means of a flanged main bearing at the propeller end, the crankshaft being allowed .004 inch to .00[illegible] inch end clearance in this bearing.

Lubrication of Gear Reduction.—In order to supply oil to lubricate the gears and bearings of the gear reduction a special metering groove is pr

vided in the propeller end crankshaft bearing upper half and oil under pressure flows from this groove during part of the revolution of the crankshaft through a radial hole in the crankshaft journal registering with same. The end of the crankshaft is hollow and is plugged at the rear end and open at the front end through a projecting spigot or jet. Oil is therefore intermittently forced out of the jet and into the interior of the hollow spur pinions. Radial holes carry the oil thence to the gears and the various bearings. Oil returned from the reduction gear flows back into the sump and is returned to the outside oil tank by means of either of the two scavenging pumps in the regular way. The oil pressure gauge connection on the geared engine is located on the left forward side of the crankcase thus registering the lowest pressure in the system, as in the case of the direct drive engines.

Inspection of Gear Reductions.—The reduction gear should not require any attention between overhauls of the engine When the engine is overhauled the gear should be opened, cleaned and inspected. The gear may be removed as a complete unit from the engine by removing the nuts and cap screws which attach it to the crankcase and oil pan. To open the gear, separate the two halves of the gear case at the split line. The driving pinion will remain in the rear half of the case and the propeller shaft will remain with the front case. The gears and bearings may be examined without further disassembly For a more thorough examination of the bearings or replacement of any parts requiring disassembly of the bearings and gears from their shafts, such disassembly should be carefully done with the special tools designed for this purpose, these tools consisting of special gear and bearing puller manufactured by the Allison Engineering Company.

If at any time it should be necessary to completely disassemble the gear, great care should be used in re-assembling to insure the bearings fitting squarely on the shafts and that these bearings are completely home. It is advisable to fit the propeller shaft gear so that the marked splines coincide and it is essential that the pinion gear should be mounted according to the marked splines. This latter is essential in order to have the oil holes in the gear register with those in the shaft. Upon the completion of the preliminary test run on a newly assembled engine, it is advisable to remove the gear and inspect it to see that it is clean and free from metal chips or other foreign pieces that may have gotten into the engine during assembly.

Inverted Engines.—The model 2A-1,500 engine is also constructed in an inverted form and differs from the standard direct drive engine in the following respects: The crankcase oil pan of the inverted engine is a simple casting merely serving as an oil tight cover. No accessories or other fittings are fastened to this cover. See Fig. 697. The purpose of this design has been to remove all possible projections on the top of the engine so as to assist the plane designer in securing the best possible vision for the pilot. The standard water, oil and fuel pump is used with certain modifications and is located low down at the rear end of the engine so as to insure correct functioning of the oil and water pumps at all times and insure that neither of these pumps fail due to lack of priming. A special adapter casting supported from the crankcase by means of the four studs used in vertical engines in fastening the magneto or generator adapter is also braced to a

bracket extending from the rear carburetor cross header. This adapter contains a vertical driveshaft with a spline drive at the upper end and a similar drive at the lower end engaging an extension of the water pump driving shaft. The scavenging oil pumps operate in conjunction with a gear keyed to the water pump shaft, as with the standard engines. A third scavenging pump is placed below and driven from the oil pressure pump, and this auxiliary scavenging pump is used to scavenge the camshaft housing covers on a glide as explained later. A coarse mesh screen entirely surrounds the scavenging pump gear housing to prevent foreign particles entering the rear scavenging pump. A standard form of fuel pump can be used with the inverted engines.

Lubricating System of Inverted Engine.—The outlet from the external oil tank is connected to the inlet of the oil pump in the usual manner and the oil flows through the oil screen to the pressure pump. Oil is discharged from the pressure pump either through the relief valve and thence back to the "out" line or through a short horizontal and a long vertical tube pressed into the adapter casting to form a matched joint at the flange where this casting is bolted to the crankcase with a short passage leading to the horizontal oil pressure manifold located in the Vee in the standard position. Oil is led to the main bearings by means of steel tubes pressed in the transverse walls as in the vertical engines and the bearing lubrication is arranged exactly as previously described. Oil is led to the camshaft bearings by means of individual pipes connected to the pressure line at the upper end of the adapter and the camshaft lubricating system is exactly the same as in the case of the vertical engines.

The scavenging or oil return system in the inverted engines is naturally quite different from that in the direct engines. The crankcase proper is drained by means of an external oil manifold located in the Vee and separately piped to drains provided under each crankcase transverse wall. This manifold discharges to the forward suction pump by means of matched passages provided in the accessory adapter. At the front end of the crankcase pipes are provided at the lowest point to return oil to the camshaft housing covers. The rear main bearing wall of the crankcase is provided with two ¾-inch drain holes at the lowest point in the Vee so as to permit of oil also flowing down over the gear train. The timing gear shaft bearings, however, are independently lubricated as in the vertical engines. Oil flowing down at the rear end of the engine can either flow through the holes provided in the wall to which the accessory drive adapter is bolted or can flow down the camshaft drive housings. In the former event the oil flows directly into the adapter housing and is scavenged by the rear scavenging oil pump. Oil flowing down the camshaft drive housings, oil discharged from the camshaft bearings, and also the oil pumped through the exhaust valves collects in the camshaft housing covers. These covers are drained by individual pipes at both the front and rear ends.

With the propeller end high, as in climbing with a tractor installation, the oil will flow to the rear end of the camshaft covers and then by short pipes to the adapter housing where it will be scavenged by the rear oil pump. Oil collecting at the forward end of the valve housing covers flows through pipes integrally mounted on each cover, these pipes being joined

together by hose connections at the rear end connecting with a short pipe which communicates with the special suction pump referred to above and mounted as an extension of the pressure oil pump. This pump serves to drain the valve housing covers on a glide and the discharge from this special pump is carried into the main discharge line by means of an external ½-inch pipe. The main discharge line should be piped through an oil cooler and back to the oil tank in the usual manner. An oil "out" thermometer should be located in the oil "out" line before it reaches the oil cooler. It will be noted that the combined water and oil pump is turned around 180 degrees when mounted on the inverted engine so that the oil strainer is located on the right hand side and the pressure relief valve is at the rear end with the fuel pump on the left hand side. The same oil tank vent is provided on the crankcase for use on the inverted engine as on the direct, but, of course, appears on the right hand side at the timing gear end.

Water Circulating System of Inverted Engine.—The water pump on the inverted engine is located at the lowest point and is provided with the same type of inlet connection as used on the direct engine, that is to say, either an elbow or a straight connection can be supplied to receive a 2½-inch I. D. hose. The water flows through the inverted engine, however, in the reverse direction as compared with the direct engine. Short hose connections connect the water pump outlet to similar inlets provided on the special camshaft drive housings. Water is forced through the camshaft housings and into the individual cylinders through holes surrounding the exhaust ports and flows around the jackets and out through the individual outlets provided on each cylinder to the water outlet manifold serving each bank. This manifold can be turned to deliver water at either the rear or forward end but it is recommended that the water be discharged at the forward end and be led into an expansion tank located above the engine to avoid any possibility of steam pockets being formed in the system. Special pains should be used in the installation to prevent any possibility of air or steam pockets being formed in the system as previously explained.

Carburetion of Inverted Engine.—The inverted model 2A-1,500 engines employ the same carburetors as used on the 1A-1,500 engines, namely, the Stromberg model NA-Y5 carburetors. The intake manifolds are of special design to permit of the carburetor being attached in the conventional manner and they are provided with exhaust-heated jackets which function in the same manner as in the vertical engines. The standard settings for these carburetors on this engine are as follows:

Choke	1⅞"
Main jet	No. 40 drill
Idle metering jet	No. 61 drill
Idle air bleed	No 40 drill

Water Outlet Thermometer.—In the case of the inverted engine it is necessary to provide for a water outlet thermometer connection in the expansion tank and this should be located so as to receive the direct flow of water from the engine.

Packard 24-Cylinder X Engine.—An informative discussion on the Packard racing engine was published in the July, 1928, *S. A. E. Journal* by L.

M. Woolson, aeronautical engineer for the Packard Motor Car Company and the information that follows has been taken from that article. Development of the Packard X engine began about eight years ago, when power plants for the dirigible Shenandoah were first being considered. It was decided to use six-cylinder-in-line engines, which were heavy. Originally the Shenandoah was equipped with six engines, each developing 300 brake horsepower and each weighing approximately 1,200 pounds. The Model 2,500 engine, rated at 800 horsepower and weighing substantially the same as the foregoing 300 horsepower engine, was being developed at the time

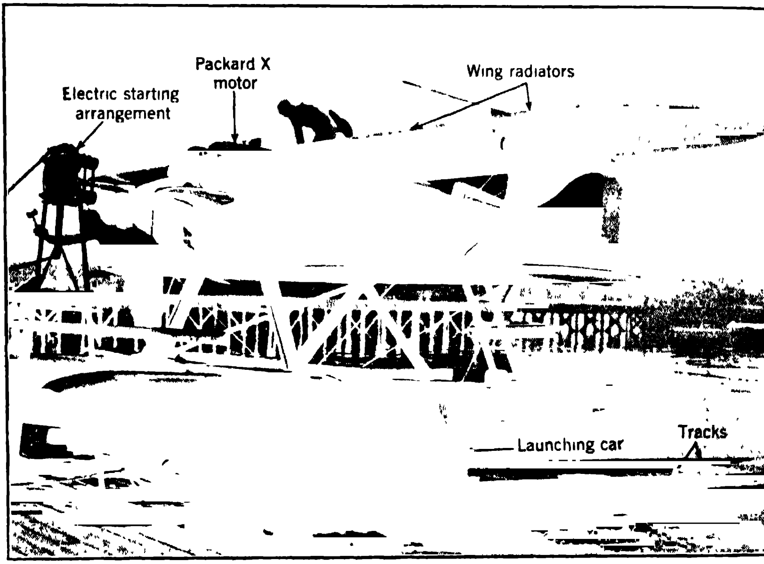


Fig. 704.—Illustration Showing Packard X Engine Mounted in Lieut. Al Williams' Racing Seaplane. Note Method of Building Engine Into Fuselage Structure.

the Shenandoah was wrecked. With a conservative rating of 600 horsepower, it would have cut down the powerplant weight approximately one-half. Comparing the present Packard X engine with the five engines used on the Shenandoah during most of her flights, it weighs approximately 1,500 pounds, develops approximately 1,500 horsepower, and could have replaced all five of the former engines at approximately 25 per cent of their combined weight.

The engine borrowed from the Navy Department and used by Lieut. Alford J. Williams, U.S.N., for obtaining flight experience and for powering the special plane in which he tried to win the world's speed record, was not equipped with a supercharger. The unsupercharged engine developed 1,250 horsepower at 2,750 r.p.m. and weighed slightly less than 1,400 pounds. During the 30 hours of operation to which this engine was subjected, mostly at racing speed, at no time was mechanical trouble experienced or adjustments of any kind made. It is planned to substitute the supercharged engine in the plane later, it being obvious that the speed will

thereby be considerably increased. The engine develops about 160 horsepower per square foot of frontal area which is remarkably small, as can be seen by referring to front view at Fig. 705 A and B.

During the last year or two, aviation authorities have been prone to overlook basic requirements of powerplants in respect to their frontal area. It is a fact that a 200 horsepower radial air-cooled engine cowled into a cabin plane makes a very excellent combination. The projecting cylinders in this case do not constitute such a grave additional resistance as they would in the case of a fuselage of smaller dimensions. On the other hand, a 200 horsepower engine is naturally limited as to the load which it can be expected to carry. The record—set, Mr. Woolson believes, by the late Mrs. Grayson in a certain flight—amounted to 6,000 pounds per engine or a loading of about 30 pounds per horsepower which he thinks is a world's record

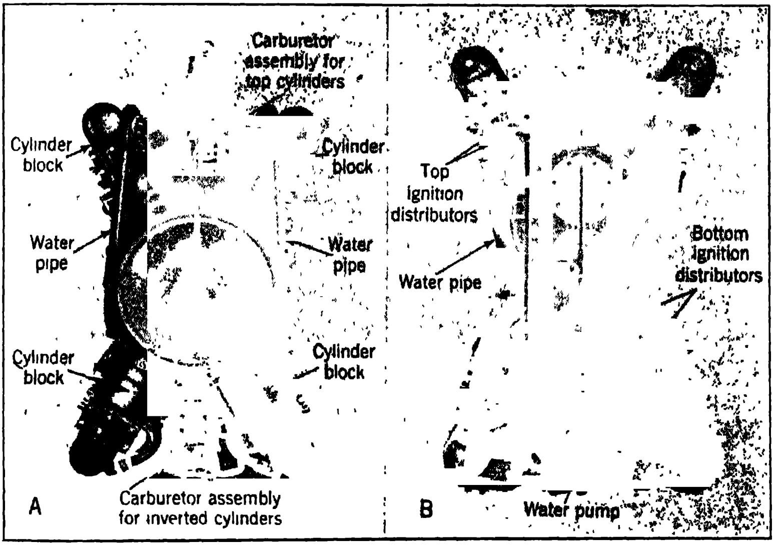


Fig. 705A.—Propeller End of Packard X 24-Cylinder Water-Cooled Engine. B—Anti-Propeller End Showing Ignition Distributors.

for planes outside of the light-plane class. Applying this same ratio to the Packard X-type engine, it should be capable of taking into the air a plane weighing 45,000 pounds, which is larger than anything yet built using only one engine. Small radial air-cooled engines are very well adapted for moderate loads; but, as the demand grows for heavier loads and higher speeds, much larger engines will be required, and they must be suitable for well-streamlined fuselages, as is imperative in racing planes, as shown at Fig. 704, which shows a Navy experimental racer that made over 300 miles per hour with a wheel landing gear replacing the pontoons or seaplane floats shown in the illustration.

The cylinder construction used, as shown at Fig. 705, has been typical of Packard aircraft engines for several years. The cylinders are built-up from steel forgings welded together, with all welds arranged so as to be

subjected to no excessive alternating stresses. The novel features of the cylinder design lie in the fact that the valve seats are entirely surrounded by water and that water space is provided above the combustion-chamber and below the top plate of the cylinder. The cylinder-head is therefore extremely rigid, resisting deflection and assuring the maximum integrity of valve seats. The valve ports are machined integrally with the cylinder-head and are not welded thereto as in the case of the Liberty engine cylinder. The water jacket is wrapped around the cylinder, thus requiring a single vertical welded seam. The bore of the X-type engine is 5⅜ inches and the stroke is five inches.

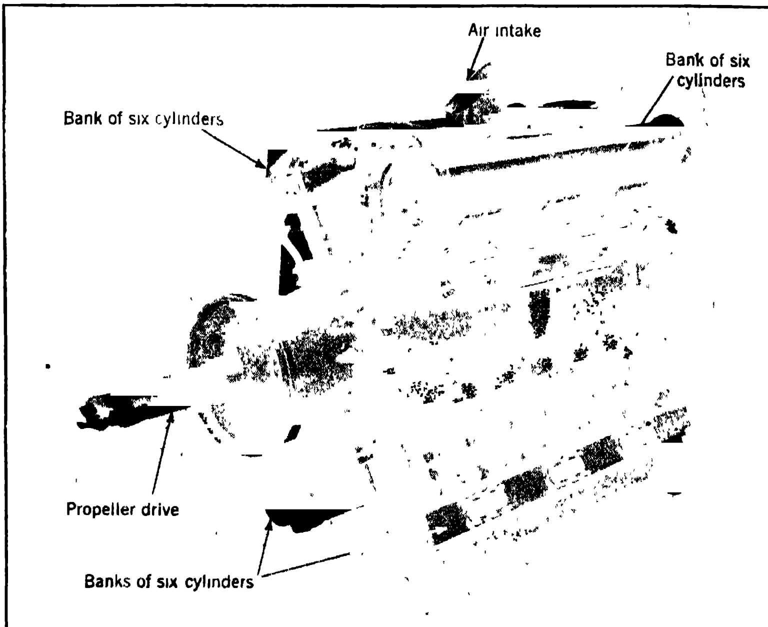


Fig. 705C.—Three-Quarter View of Packard 24-Cylinder X Engine Viewed from Propeller End.

The relative arrangement of the valve housing and water inlet and exhaust passages is contrary to conventional practice. While there are four valves per cylinder, two inlet and two exhaust, they are arranged in pairs athwartship, rather than on a longitudinal axis as is usual. The reasons for this construction are, first, to secure a simple valve-mechanism with a single camshaft to operate all the valves of each bank of cylinders; second, because the valve-housing casting is considerably simplified by this arrangement and it is possible to siamese the inlet and exhaust ports, respectively, of adjacent cylinders, thus minimizing the number of separating walls required in the casting.

The piston design shown in Fig. 706 incorporates extremely short skirts the over-all length of the pistons being 3.164 inches for a diameter of 5.37

inches. These compact pistons materially assist in reducing the over-all height of the engine, and they have proved very satisfactory during several years of service operation in other Packard engines. The fuel lines were designed with the idea of reducing the fire hazard to the minimum. They consist of one-piece annealed copper pipes having no brazed or soldered fittings or flaring operations. At all important points drop-forged-steel fittings are provided, with integral "olives" or protecting sleeves to prevent rubber particles from entering the gasoline lines, and each line is enclosed in a one-piece rubber hose extending from one fitting to another, hose clamps being provided at frequent intervals so that, even if a gasoline line should break, no external leakage of fuel would result.

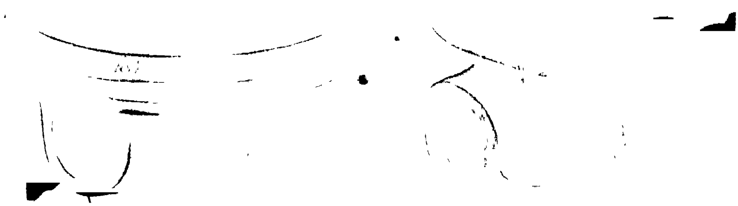


Fig. 706.—Packard X Engine Alloy Piston Has Extremely Short Skirts, the Length Being Only About Three-fifths or 60 Per Cent of the Diameter.

The battery ignition distributors are shown also at the right in Fig. 705 B. Four twelve-cylinder distributors of conventional design are used, each distributor being wired to two of the four banks of cylinders. Each cylinder is provided with two sparkplugs, making a total of 48, and a high order of ignition reliability is thus obtained. The oil, fuel and water pump assembly is shown in the lower portion of the view at Fig. 705 B. The vertical pipe at the rear of the engine constitutes the high-pressure oil-supply line; a branch to the left supplies the main-bearing oil manifold at reduced pressure. The propeller end of the engine is shown at Fig. 703 A and a three-quarter assembly view is given at Fig. 705.

QUESTIONS FOR REVIEW

1. What type of cylinder construction is used on Packard Aviation engines?
2. Describe Packard crank case construction
3. What are the advantages of the Packard valve housing?
4. How are Packard exhaust valves cooled?
5. Describe Packard oiling system
6. What types of ignition systems are provided with Packard engines?

CHAPTER XXXIX

TYPICAL LARGE WATER-COOLED ENGINES

Economy an Important Factor—Future Engine Development—Prophets are Sometimes Wrong—The Junkers Aviation Engines—A.D.C. 300-330 HP. Nimbus Engine—Mercedes-Benz Type D 11a Engine—Beardmore Six-Cylinder Engine—The B.M.W. Va Aero Engine—B.M.W. VI Engine—Lorraine W Type Engine—Panhard Sleeve Valve Type 12L Engine—Rolls-Royce F Type Aero Engine—Rolls-Royce Condor III A Aero Engine—New Series Renault Motors—Salmson Water-Cooled Radial Engines—Napier-Lion Aero Engine—Napier "Cub" Aero Engine—Fiat AS3 Racing Engine—Issotta-Fraschini Vee Type.

Economy an Important Factor.—The modern ideas of aviation have brought the question of economy more and more into the foreground and led to a sharp differentiation between military and commercial airplanes While, in the case of military airplanes, up to 100 per cent of the output of the engines is utilized, in order to meet the demands made on the machine, only that percentage of the maximum engine output should be made use of as normal output for commercial machines, as is permissible from the standpoint of reliability and economy. For commercial airplanes the normal output of any engine type should be about 50 to 60 per cent of the maximum output, long life of the engine, reliability, a large profitable useful load, great radius of action, and thus also economy being attained It is only then possible to build commercial airplanes, the ceiling of which is sufficient to carry out flights in all weather and to attain altitudes, in which the atmospheric and wind conditions are more favorable. It is also very important for the reliability of the plane that the engine power is divided into several units for large planes for long-distance flights. With such planes it must be possible not only to keep in the air at low altitudes, but also to reach reasonable altitudes, even when one, or, in the case of the very large planes, two or more engines break down. It is a specially great advantage for multi-engined planes to have engines with a normal output of 50 to 60 per cent of the maximum output, as the engine can, without danger, be used with an output of 120 to 125 per cent of the normal output.

In order to achieve the greatest possible output with a certain predetermined cylinder capacity, the compression ratio would have to be increased to the utmost limit. For this purpose, however, it is essential that the fuel is improved, because, as the very best material is just good enough for the manufacture of aero-engines, only the very best fuel should be used for driving them. It is incorrect to hold the engine experts and steel specialists alone responsible for progress in this line. The fuel specialists must also do their bit in the development of the engines. One must (and can) demand from the fuel producers that they are not satisfied simply to utilize the progress made in aviation for increasing their turnovers, but that they also take an active part in the development of suitable fuels The principle should be, to make such improvements that fuels vaporizing

at low temperatures can also be used for engines with compression ratios up to ten, without knocking. At present, it is already possible to improve fuels to such a degree by adding a suitable proportion of benzol or special "anti-knock" dope that no knocking occurs with a compression of 7.3:1.

When fuels are produced which do not cause knocking with high and highest compression ratios, these ratios should be employed as standard for aero-engines, and engines with low compression ratios should only be built for special cases, when anti-knock fuels are not procurable.

Future Engine Development.—Turning now to possible future developments it may be of interest to speculate toward what direction progress in aircraft engines will lead. Problems to be solved in this field are well known and consist largely of detailed improvements intended to yield lighter and more reliable engines that will be more economical with respect both to first cost and to operation and maintenance. Although much experimental effort in engine development is being continually directed along unconventional lines, such as the barrel and cam types, and engines employing the Diesel or semi-Deisel cycle, it is reasonable to believe that during the next few years important advances will be made by conventional twelve-cylinder water-cooled engines and by nine-cylinder fixed-radial air-cooled engines, the two types that offer the best possibilities for immediate engineering advance and where very high powers are required from a single motor the X form of 24 cylinders, the W form of eighteen cylinders and the double banked nine-cylinder or eighteen-cylinder radial air-cooled engines are all possibilities that have already been realized in experimental types.

It is reasonable to look forward to having available in the near future engines that will weigh about one pound per horsepower completely equipped and, concurrently with this development, considerable effort will undoubtedly be devoted toward reducing the specific fuel-consumption. For it should be borne in mind that an engine weighing one pound per horsepower will, at the present rate of fuel-consumption, consume its own weight of fuel every two hours. Doped fuels and higher compressions will make possible higher power outputs for a given cylinder displacement. Ethyl-gas is said to permit the use of pressures up to 150 pounds per square inch before ignition without risk of premature ignition or detonation after ignition. The compression limit with aviation gasoline is about 110 to 120 pounds, so a 25 per cent increase in mean effective pressure is possible without changing engine designs other than augmenting the compression and increasing strength of parts to withstand augmented stresses produced by increased explosion pressures.

Some of the latest developments in connection with high-speed oil engines in England were bared at a session of the British Association for the Advancement of Science, at which a paper on the subject was read by A. E. L. Chorlton, of W. Beardmore & Co., Ltd. Mr. Chorlton said that for aircraft purposes an oil engine must develop a brake mean effective pressure of at least 100 pounds per square inch, and 120 pounds is preferable. It is therefore necessary to utilize practically all of the air entering the cylinder for the combustion of fuel. The relative amount of excess air passing through the engine also has an important effect on the economy.

While the fuel spray must completely permeate and penetrate the air charge, there must be no interference, and this makes it necessary to consider whether it is better to use a single spray jet or several, and in the case of a single jet, whether it is best to mount it in the center of the head or elsewhere. A number of different jets in a single combustion-chamber assure quick combustion, but there is danger of interference.

After extended experiments, Wm. Beardmore & Co. developed a satisfactory engine of the heavy oil type, and some results obtained with it were given in an Institute of Mechanical Engineers paper in March, 1926. In the tests then reported upon, the engine was shown to have a specific fuel consumption of 0.35 of a pound per brake horsepower hour. Since that time further improvements have been made, and recently a fuel consumption figure of 0 32 of a pound per brake horsepower hour was reached, with an eight-cylinder engine of 8¼ inch bore and twelve inch stroke, developing 650 horsepower at 1,000 r.p.m. This is equivalent to a thermal efficiency of 40 per cent. The engine structure is in a single casting, and if steel is used the weight is 4,600 pounds, while with aluminum it is 3,600 pounds. The weight horsepower ratio of about six pounds per horsepower would seem to be a disadvantage even considering the low fuel consumption. The Packard Motor Car Co. of Detroit have recently announced a nine-cylinder radial Diesel engine that weighs but three pounds per horsepower but the engine was not ready for the market as late as March, 1929.

Prophets are Sometimes Wrong.—The way that changing conditions in any new industry will change the thought of those connected with it as they gather experience can be well illustrated by the way some early predictions have failed to work out and also illustrates the dangers of prophecy on the printed page. An English aviation engine authority, writing in 1916, said: "We have dealt principally with engines of 100 horsepower but engines of 200 horsepower are in common use and in the near future we may expect still more powerful engines—probably the day of the 1,000 horsepower airplane engine is close at hand." He was right in his prediction in that statement anyway. He goes on to say, "One is frequently asked to state which type of engine will survive, and the six- or twelve- or eighteen-cylinder vertical-in-line type will most likely come out on top. The radial and rotary type have too much wind surface exposed and have as a rule, to be placed in front of the pilot; the Vee engine is not an attractive mechanical proposition and the advantage gained by the reduction in engine length is partly discounted by the increased width and other disabilities mentioned previously. The use of ball bearings for main engine bearings is a doubtful advantage. The abolition of the oil pump with its attendant drive and pipes may also be one of the future developments in design. In the matter of pistons the cast iron article holds a prominent place in spite of the introduction of aluminum alloys The overhead camshaft is not in favor as it introduces new troubles to add to other misfortunes."

Analyzing this opinion in the light of our present knowledge gives some rather amusing results. We have no twelve-cylinder in-line aviation engines and an eighteen-cylinder installation would call for a forwardly

extending engine mounting almost as long as our present rearwardly extending airplane fuselage, not to mention the designing and construction problems incidental to the fabrication of an eighteen-throw crankshaft which would have to run in from ten to nineteen main bearings. Our prophet was way off in that belief. He was also wrong in his prediction that Vee engines would not be used because they were too wide, most engines of the water-cooled forms with more than six cylinders are twelve-cylinder Vee types and the fact that width is not the factor but that engine length must be kept to the minimum is proved by the use of twelve-cylinder and eighteen-cylinder W types.

The disadvantage he quoted of radial and rotary motors having too much wind surface exposed did result in doing away with rotary engines which were difficult to cowl but the main factors that did result in doing away with rotary radial cylinder engines was the limited speed of rotation of about 1,250 r.p.m.; the fact that it introduced gyroscopic forces affecting control and the habit these engines had of throwing burnt castor oil into the propeller slipstream and all over the pilot and airplane structure. The greatly increasing use of static radial engines in nine-cylinder forms up to 600 horsepower and in double bank or eighteen-cylinder forms up to 1,000 horsepower shows that a proper study of fuselage form and engine cowling permits the modern airplane designer to use a wide and short fuselage so streamlined that its resistance is actually less than the longer, attenuated, narrow section fuselages of the earlier time. Most radial engines and some in-line and Vee and W types use ball and roller bearings very advantageously for crankshaft support, so our prophet was wrong in that matter. The use of aluminum pistons is now general and engines using cast iron or steel pistons would be a novelty. Most aviation engines of the six-cylinder in-line type and practically all Vee and W engines use overhead camshafts to the exclusion of other means of valve actuation and no great trouble has resulted. Finally, after over twelve years of added experience since the prediction was made, no one has had the courage to eliminate the oil pump and its attendant drive and pipes! Experts of to-day may be quite wrong tomorrow.

As regards engine placing in front of the pilot, which was not so satisfactory to the early prophet when rotary engines were installed with their oily exhaust blown back in the slipstream, modern practice, as a result of changed conditions, has made the forward mounting of the engine general practice and most pilots of experience actually prefer to sit back of the engine rather than in front or under it. Modern designers believe in the slightly nose heavy plane and the placing of the engine at the front of the fuselage is common practice and other locations, when a single engine is used, are the exceptions that prove the rule. It will be apparent that a motor location that was considered a disadvantage in 1916 is now popular, and the radial cylinder engine, which was not in favor because it had much surface exposed to the wind, has utilized this surface to cool the engine instead of having supplementary exposed surfaces, such as water radiators, to do it, thus greatly saving weight and reducing mechanical complication. The discovery that a fuselage having the shape of an elongated egg had less resistance than a long fish shape showed that by proper cowling of

the engine employing a wide fuselage, providing it had a good length breadth ratio, made it possible to install radial engines and Vee or W types more advantageously than long in-line engines could be placed.

The Junkers Aviation Engines.—The Junkers L5, a six-cylinder water cooled in-line engine has received considerable publicity because it made the first successful Atlantic crossing from East to West as the power plant of the Junkers all metal monoplane, the Bremen. The plane has a span of 60 feet and a total length of 35.78 feet, while the overall height is ten and one-half feet. Both the fuselage and the wings have a covering of corrugated duralumin. Without load the machine weighs 2,920 pounds and the

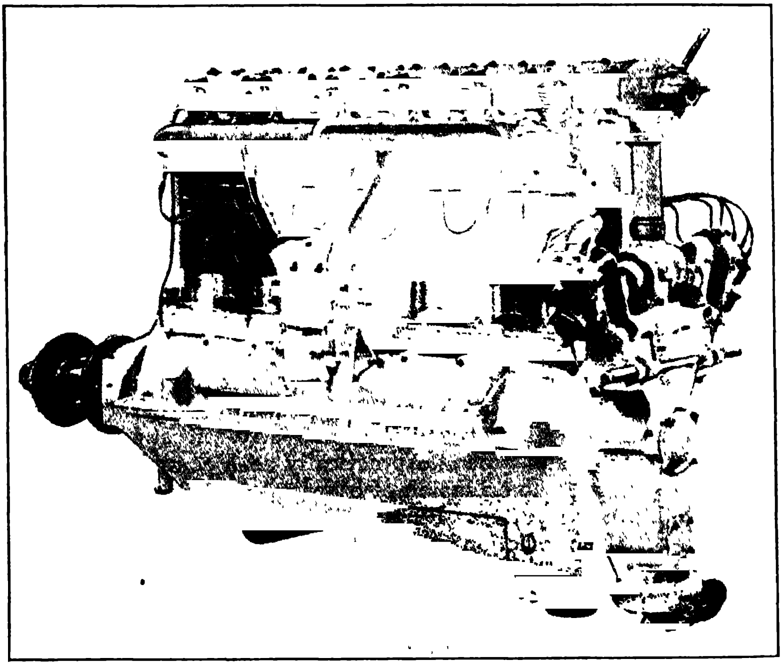


Fig. 707.—The Junkers L5 Six-Cylinder Water-Cooled Type Used in "Bremen" Airplane, First to Make Westward Passage Over Atlantic.

initial load carried by the plane was 5,150 pounds or 176 per cent of the weight of the machine. The Bremen is similar in design to machines built by the Junkers Works for passenger and mail services. The stock machines are equipped with floats for landing on the water, but in the trans-Atlantic plane these were replaced by the ordinary wheeled landing gear.

The commercial machines have a hold with a cubical content of 57.5 cubic feet. In the Bremen this space was used chiefly for additional fuel tanks. There are also fuel tanks inside the wings and there is a large oil tank at the side of the engine. Whereas in the ordinary planes the pilot's compartments are open, in the Bremen it is inclosed by sheets of cellon.

The engine of the Bremen shown at Fig. 707 is the Junkers Model L5, a six-cylinder vertical water-cooled type with a bore of 160 and a stroke

of 190 millimeters (6.30 by 7.50 inches). It has a compression ratio of 5.5 and develops 280 horsepower at 1,400 and 310 horsepower at 1,550 r.p.m. The weight of the engine dry is 693 pounds, or 2.47 pounds per horsepower on the basis of the normal rating. Last summer, in preparation for the westward trans-Atlantic flight from Germany, a special concrete starting track was built at Dessau. This enabled the Bremen to get into the air with a total weight of 8,050 pounds after running along the track for distances varying between 1,800 and 2,100 feet. As the plane left the track the engine turned over at 1,440 r.p.m. An altitude of 150 feet was reached in one and one-half minutes, and 300 feet in three minutes, after which the engine was throttled down, but the plane continued to rise even when the speed was reduced to as low as 1,280 r.p.m.

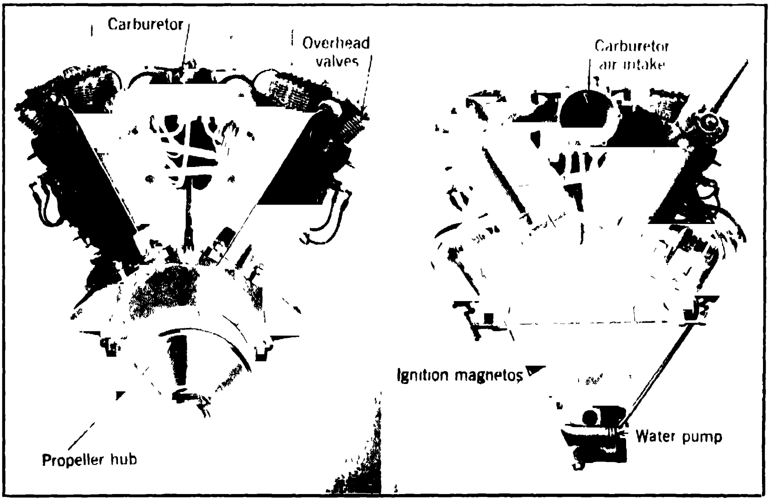


Fig. 708.—View at A Shows Propeller End of the Junkers L55 Aircraft Engine. B—Anti-Propeller End Showing Carburetor, Ignition Magnetos and Water Pump Assembly.

The cylinders of the Junkers engine are of steel with steel water jackets attached thereto by autogenous welding and in details of valve arrangement and actuation it is patterned very closely after the original Mercedes design which was the ancestor of many modern engines. The method of cylinder construction is clearly outlined in the chapter on the Liberty motor as is the method of valve actuation and camshaft drive. This engine may be obtained with a compression ratio of seven to one for use with special fuels and will deliver 350 horsepower at 1,500 r.p.m. with that high compression. The engine is built for direct drive propeller. The lubricating system is the circulating forced lubrication type. A dual carburetor is used, this being joined to a straight type manifold by two branches, as shown at Fig. 707. This type of engine lends itself to easy installation in the airplane fuselage and is a very substantial and simple engineering job. Unfortunately, the limitations imposed by length make it undesirable to use

much larger cylinders and obtain more power so these forms will be found worked out to the best advantages in designs where the power requirements range between 150 and 400 horsepower.

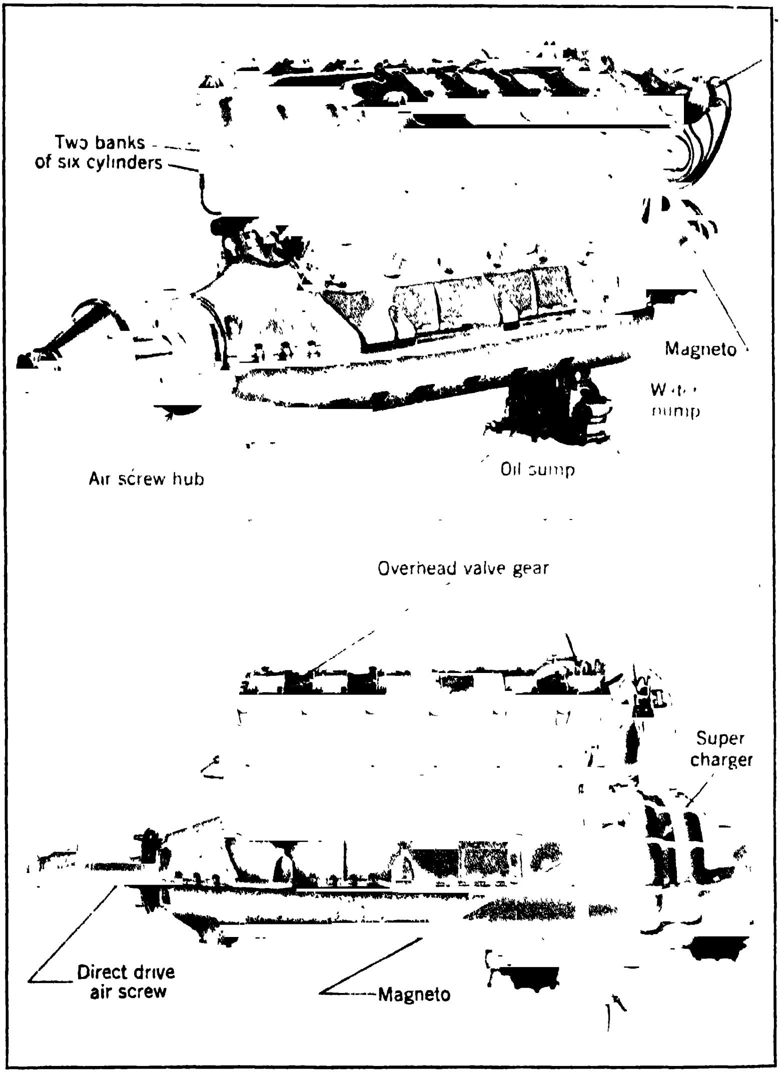


Fig. 709.—A Shows Junkers L55 (German) Engine Side View Looking at Propeller End. B is a Direct Side View with Supercharger Installed.

When more power is required, the combination of two banks of cylinders to form a twelve-cylinder Vee engine is resorted to by practically all builders of large water-cooled engines in the power range between 400 and 800 horsepower. The Junkers L55 engine, which is shown at Figs. 708

A and B and 709 A may be considered a typical standard design that has received wide application. This design is also made with a supercharger as shown at Fig 709 B. The specifications of the Junkers L55 aero engines follow:

SPECIFICATIONS - JUNKERS L55 ENGINE

Build of engine: vertical stationary 4 stroke engine, water-cooled, without reduction gear

Output at 1380 R P M.	500 Hp.		
Compression ratio.	1 5	1 5.5	1 7
Normal duration output at 1460 R P M	550	600	625 Hp
Temporary maximum output at 1500—1520 R P M	600	650	700 Hp.
Maximum revolution number	1520 R.P M.		
Weight dry without hub, air screw and exhaust-manifold	570 kg		
Weight of hub	17.0 kg.		
Arrangement and number of cylinders	12 cylinders in Vee at 60°		
Bore	160 mm		
Stroke	190 mm		
Arrangement of valve gear.	Overhead camshaft with rockers		
Camshaft drive	By vertical shaft		
Number of valves in each cylinder	2		
Length over all (without hub)	1777 mm.		
Height over all	1273 mm		
Breadth over all	840 mm		
Ignition	2 magnetos Bosh GF 12 or Scintilla GN 12/D		
Sparking plugs	Bosch V 12 12 C or vdea		
Cooling	Water-cooled cylinders		
Lubricating	Circulating forced lubrication		
Fuel consumption	220-230 gr/Hp. h.		
Oil consumption	15 gr/Hp h.		

A. D. C. 300/330 Horsepower Nimbus Engine.—The appearance of this engine illustrated at Figs. 710 and 711 follows rather closely that of the 240 horsepower Siddeley Puma, but otherwise there is little similarity as the engine departs materially in the design of all the principal component parts. Of six-cylinder in-line water-cooled type, the Nimbus has a slightly larger capacity than the Puma, the cylinder bore being 152 millimeters and the stroke 190 millimeters; the compression ratio has been raised to 5.4 to 1. The brake mean effective pressure is high, i.e., around 132 pounds. In comparison the dry weight of the Nimbus is ten pounds less than that of the Puma, the weight per horsepower being two pounds as against 2.66 pounds per horsepower for the Puma—a very marked advance. The Nimbus engine may be regarded as the lightest of its type yet produced.

Constructionally the Nimbus differs very considerably from the Puma, although it is designed to fit the same engine bearers. The steel cylinder liners pass through the bottom of the water-jacket blocks, one of which is shown at Fig. 712, a neat gland arrangement being provided for making a water-tight joint. A split locking ring of phosphor bronze is threaded to correspond with the threads on the cylinder liner, a steel strap tightened by a tangential bolt forcing the threads home, and a rubber ring, on being compressed, making a tight joint between cylinder and jacket as shown

at Fig. 675 A. At the top, the cylinder liners are secured to the cylinder head castings by the valve seatings, which are of special design and splined on the inside for the special tool used for screwing them home as shown at Fig. 713 B. The water jackets are in the form of two aluminum castings, each jacket enclosing three cylinders. At the top the water

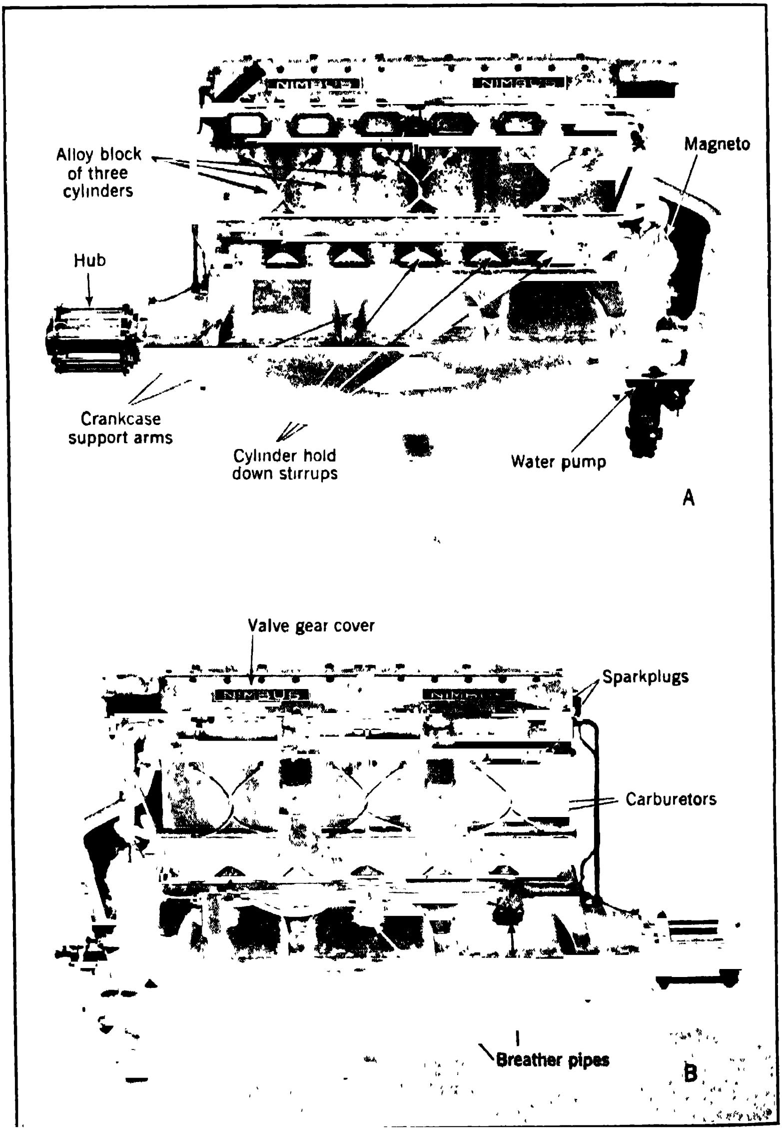


Fig. 710.—Exhaust Side of ADC "Nimbus" (English) Engine Shown at A. Carburetor Side View of "Nimbus" Six-Cylinder Engine at B.

jackets are secured to the cylinder heads by a number of bolts, the faces of jackets and heads being machined to make a tight joint. The cylinder heads, in addition to leaving a large water space around the hottest parts of the engine, are particularly open castings, so that during manufacture inspection is greatly facilitated and machining operations are reduced to a minimum. As in the Puma there are three valves per cylinder, one large inlet valve and two exhaust valves. The inlet valves are operated by short

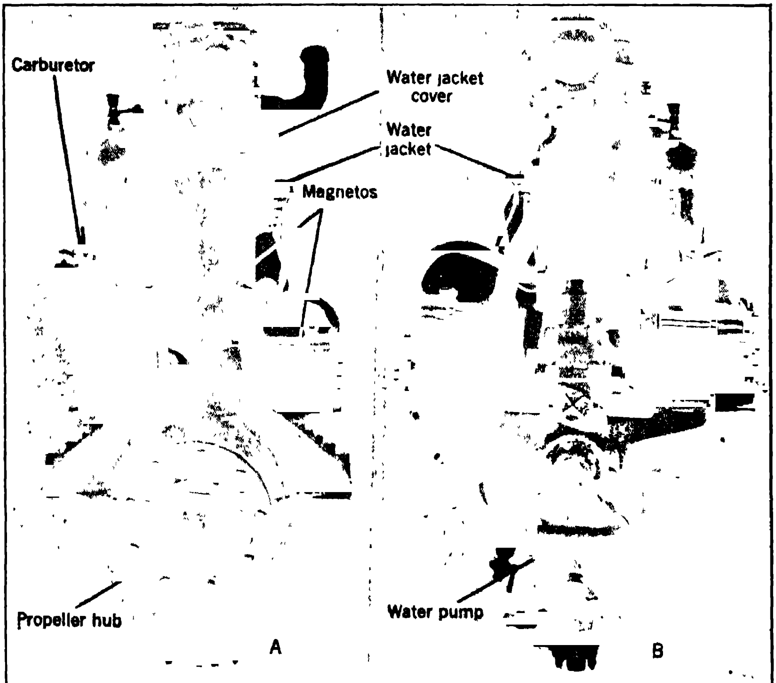


Fig. 711.—Propeller End View of "Nimbus" Aircraft Motor at A. Anti-Propeller End of ADC "Nimbus" Engine Shown at B.

rockers, while the exhaust valves are operated directly from the overhead camshaft. The valve stems have been considerably lengthened so as to give room for longer valve springs, the lift of the valves being rather greater than in the Puma.

Aluminum alloy pistons of new design are employed, and although they are of larger diameter, they are actually lighter than the original. This also applies to other reciprocating parts which, in spite of the greater power developed, are lighter than those of the original engine. The overhead valve gear remains substantially the same as that of the Puma. The connecting rods are of the same type as those of the original engine, but are of slightly different dimensions. The crankshaft is of a heavier type than that employed in the Puma engine. The induction system is a particularly simple one, with two carburetors feeding three cylinders each.

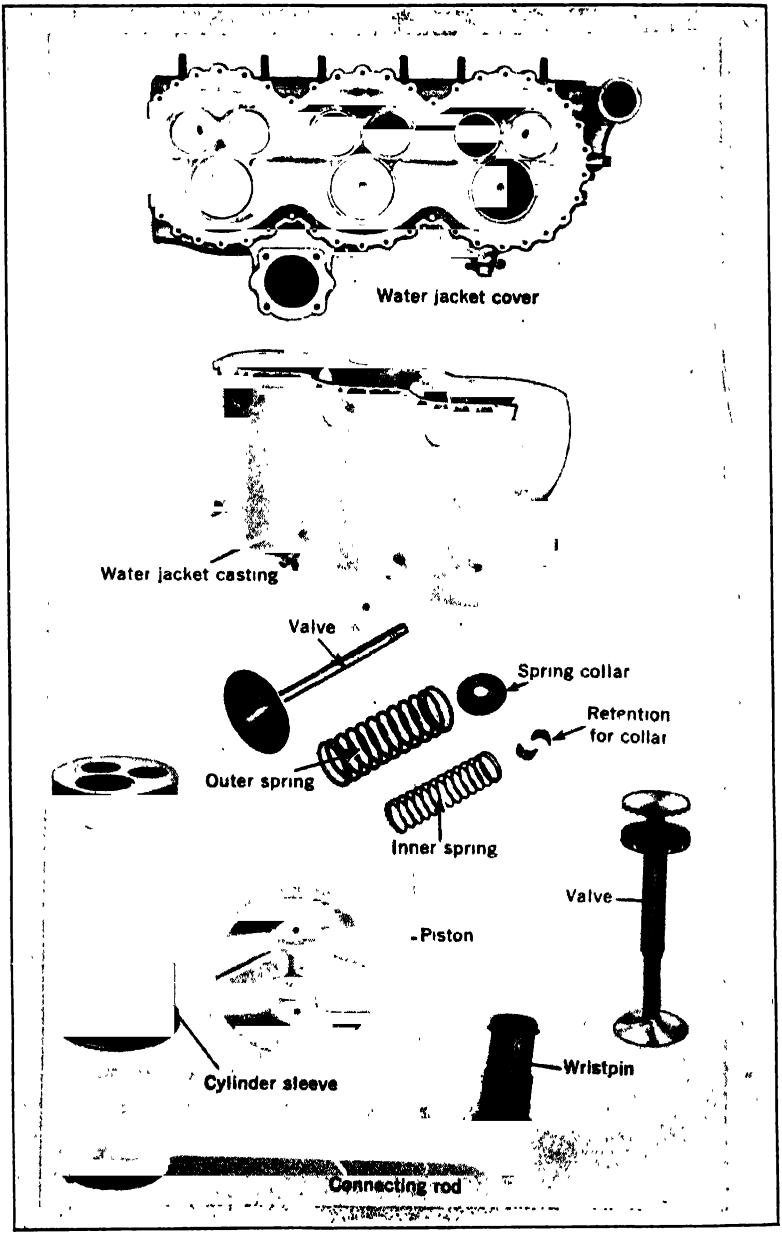


Fig. 712.—Photographs Showing Structural Details of ADC "Nimbus" Engine. Cylinder Head Shown at Top and Cast Alloy Water Jacket Group for Three Cylinders Below it. Other Views Show Inlet and Exhaust Valve Construction, and Cylinder Shell or Sleeve, Piston and Connecting Rod and Wristpin.

The objectives attained in the design of the Nimbus engine may be tabulated as follows:

1. *Low Weight Per Horsepower—Two pounds.*
   Actually the Nimbus is the lightest engine of its type ever produced.
2. *Low Petrol Consumption:*
   During the Air Ministry type test (officially observed by A.I.D.) the Nimbus engine demonstrated a phenomenally low combined petrol and oil consumption which, the makers have reason to believe, constitutes a low figure record for any engine run on an Air Ministry type test.

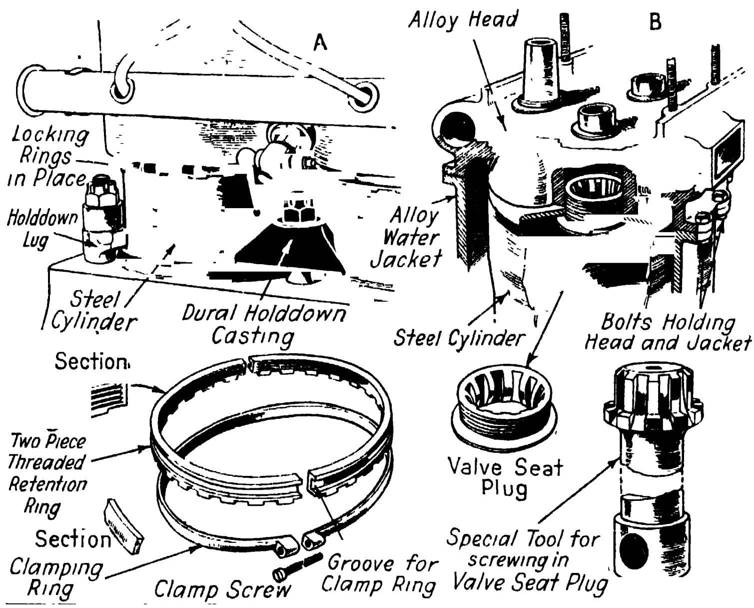


Fig. 713.—Sketches Showing Method of Holding Cylinders of "Nimbus" Engine to Crankcase and Water Jacket to Cylinder at A. B Shows Valve Seat Plugs Holding Cylinder to the Head.

3. *Minimum Head Resistance:*
   As shown in illustration.
4. *Easy Installation:*
   Interchangeable with the Puma engine.
5. *High Efficiency and Reliability:*
   Demonstrated during Air Ministry type test and hundreds of hours' running in the air and on the bench.

Endurance power was remarkably demonstrated by the engine, which, after completing the type test, ran for one hour at full throttle and maximum r.p.m., i.e., 1,600. At the commencement of the latter run the engine was giving 327.5 which improved until the engine was finally holding 335.6 brake horsepower at the end of the hour. A further hour was run at 1,680

r.p.m. as a high speed test to demonstrate the overload capacity of the bearings and valve gear. The slow running test averaged 300 r.p.m. over ten minutes running.

SPECIFICATION

Type	Six cylinder, vertical, direct drive
Cooling	Water
Bore	152 mm.
Stroke	190 mm.
Normal R P M	1450
Maximum R P M	1600
Normal B.Hp	305 at 1450 R P.M.
Maximum B.Hp	335 at 1600 R P.M.
Petrol consumption at 305 B Hp at 1450 R P M.	.52 pints per hp hour .295 liters per hp hour
or	.49 lbs. per hp hour .222 kg per hp hour
Petrol consumption when cruising at 270 hp at 1450 R P M..	.51 pints per hp. hour .289 liters per hp hour
or	.48 lbs per hp hour .218 kg per hp hour
Oil consumption	.017 pints (.009 liters) per hp. hour
Compression Ratio	5 4:1
Weight dry (complete with airscrew boss, but minus radiator and water)	670 plus or minus 10 lbs. (304 plus or minus 4 55 kg)

Air Ministry Type Test (officially observed by A.I.D.).

The Nimbus engine has passed the Air Ministry type test Outstanding features demonstrated by the engine during this extended running on the type test were as follows:

Average petrol consumption during type test at $^9/_{10}$ths power, viz: 270 horsepower at 1,450 r p.m.:

.505 pints or .474 lbs. } per horsepower
.286 liters or .214 kg. } hour.

Average oil consumption during type test at $^9/_{10}$ths power, viz: 270 horsepower at 1,450 r.p.m.:

.017 pints or .019 lbs. } per horsepower
.009 liters or .008 kg. } hour.

Mercedes-Benz Type D11a Engine.—This is a six-cylinder water-cooled engine of 120 horsepower and is clearly shown at Figs. 714 A and B. In accordance with the requirements with which this engine has to comply, on account of its purposes, the materials employed in its construction are of the highest quality and submitted to the most severe tests, prior to their use. The design of this engine, in which are embodied the results of several decades of practical experience, guarantees the highest possible degree of reliability, with a minimum of maintenance, in spite of its extreme simplicity of working and supervision.

The upper and the lower halves of the crankcase are made of aluminum. The chrome nickel steel crankshaft runs in four white metal bearings. The six steel cylinders of 125 millimeter bore and 150 millimeter stroke are mounted vertically in pairs on the crankcase. Water jackets are welded on. In each of the cylinder heads, directly over the aluminum pistons, are fitted a pair

of inverted vertical chrome steel valves for each cylinder, which are operated by overhead camshaft. The camshaft is driven from the crankshaft through bevel gears and an intermediate shaft, which also drives, through bevel gears, two "Bosch" magneto ignition sets. Two plugs per cylinder are fitted. The magneto ignition sets are provided with hand controlled timing and are adjusted for advanced ignition by spring tension. The water pump and the oil pump are also driven from the crankshaft through

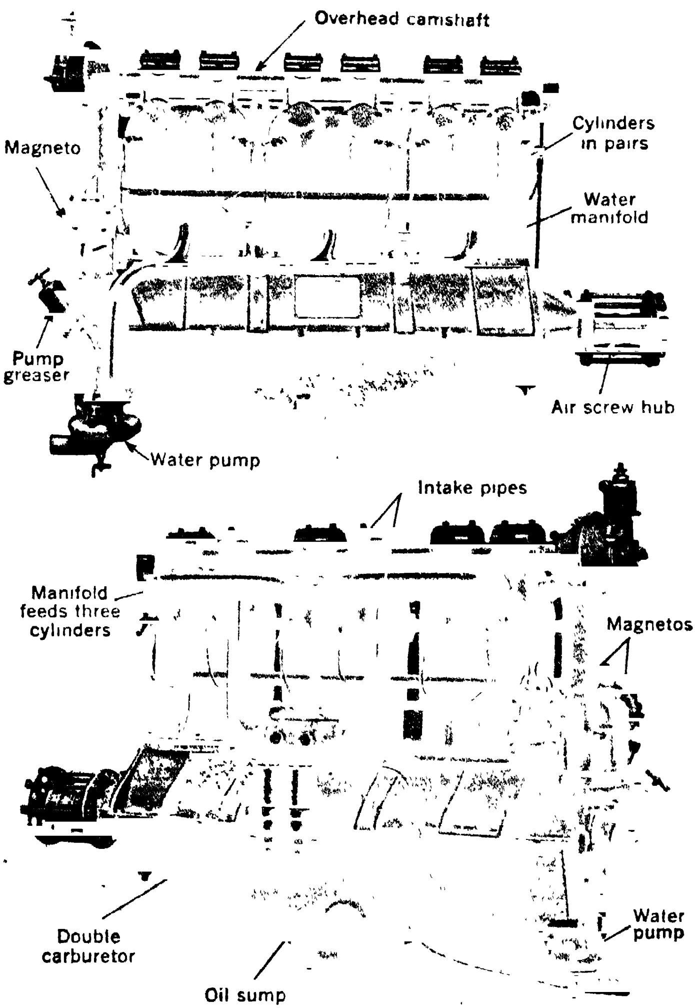


Fig. 714.—At Top, Exhaust Side of Mercedes-Benz (German) D11 Engine, a Six-Cylinder In-Line Form Having Cylinders Assembled in Pairs. The Bottom View is the Carburetor Side of the Same Engine.

the intermediary of a vertical secondary shaft through bevel and helical gears respectively. The centrifugal pump maintains a continuous circulation of cooling water through the cylinder jackets and through the heating jacket of the "Mercedes-Benz" double carburetor towards the radiator. The carburetor is fitted with a device for automatic adjustment of the supply of additional air. The oil pump is fitted in the lowest part of the crankcase and forces a continuous supply of fresh oil to the main crankshaft bearings the big-end bearings, the gudgeon pins and the camshaft bearings, while the lubrication of the pistons is effected by splash. The oil which flows back into the crankcase is filtered and returns to the pump. An oil level regulating pump which works in connection with the oil circulation pump adjusts automatically the proper level of the lubricant in the crankcase, which can be ascertained by means of a cock and of a glass level gauge.

The engine is started by means of a "Bosch" starter magneto. The fuel is fed into the carburetor under pressure by a small reciprocating air pump which is fitted above the vertical secondary shaft and driven by the latter. The principal dimensions and figures of performance are indicated by the table below:

SPECIFICATIONS—MERCEDES BENZ D11

Number of cylinders	6
Bore	125 mm.
Stroke	150 mm.
Capacity of cylinders	11,045 ccm.
Length	1450 mm
Width	500 mm
Height	1150 mm.
Normal number of revolutions	1450
Useful power	130 Hp.
Useful power for an atmospheric density of 1.25	136 Hp.
Fuel consumption per HP-hour	230 grams
Oil consumption per HP-hour	15 grams
Dry weight of the engine	200 kilos
Weight of propeller boss	4 kilos
Water capacity	10 liters
Oil capacity	6 liters

Beardmore Six-Cylinder Engine.—While it is not possible in a book of this character to describe all known aviation engines, a recent British type is noteworthy in that it is an extremely large cylinder high-powered type. It is said to be one of the largest aircraft powerplants yet constructed and is a six-cylinder form as illustrated at Fig. 715. The cylinders are 8⅝ inch bore and twelve inch stroke with a compression ratio of 5.25 to 1. The dry engine weight is given at 2,150 pounds. The overall length of the unit is 80.3 inches with a maximum width of 35 inches, while the overall height is 60.37 inches, with a total height above the center-line of the crankshaft of 45.25 inches, and a maximum depth to the lowest point below the crankshaft center of 15.12 inches. The engine is water cooled and a circulating pump is fitted. The ignition system is in duplicate, and two magnetos are employed. As illustrated, the engine is designed for a left-hand tractor-type propeller running at a normal speed of from 1,220 to 1,350 r.p.m. according to the power it is desired to develop.

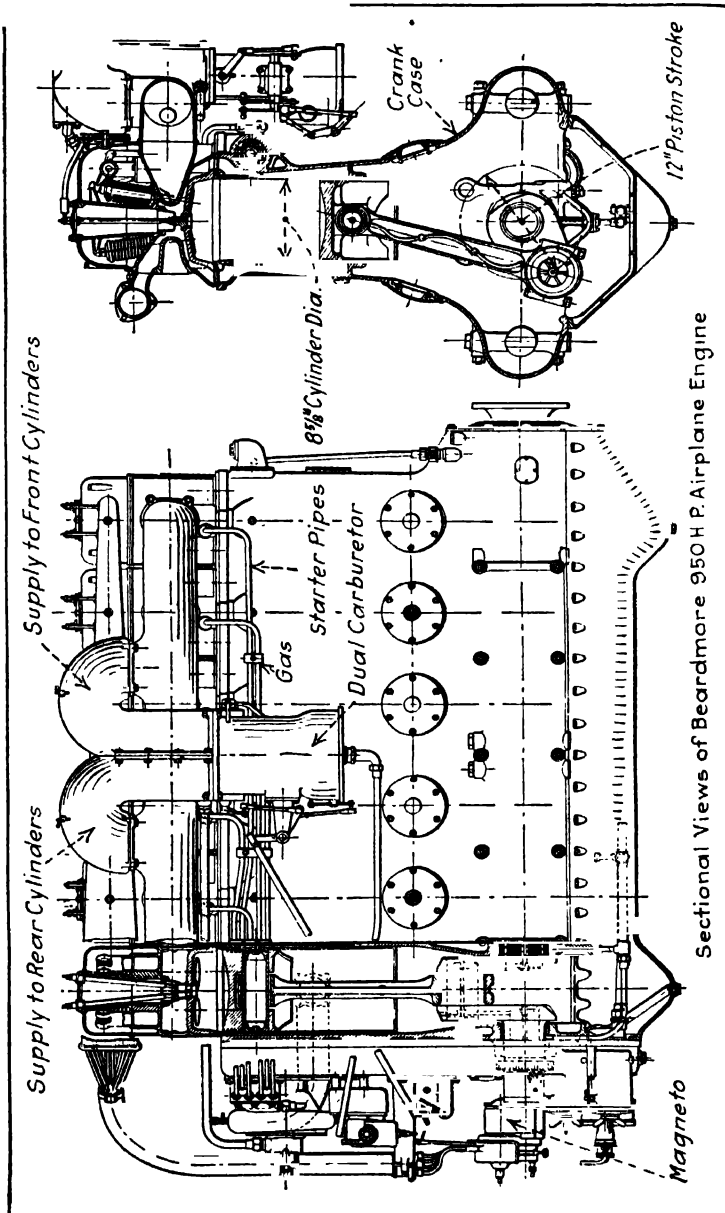


Fig. 715.—Sectional Views of Beardmore (English) Six-Cylinder Aircraft Engine, Rated at 950 Horsepower, 8⅝ Inch Bore and 12 Inch Stroke, the Largest Six-Cylinder Type to be Built for Aviation Use.

In getting out the new design the object in view was to develop as high a power as possible in a few cylinders. It was also sought to reduce the number of engine parts while rétaining the maximum accessibility. An outstanding feature of the engine is its compact and clean outline, which enables it to be installed in a very narrow fuselage, thereby reducing considerably the amount of head resistance which would be offered by an engine either of the radial or the Vee type. The crankcase, which is made in aluminum, forms the main engine body. It incloses the crankshaft and its bearings, which are carried on transverse girders, while the camshaft is accommodated in the top part of the casing At the level of the crankshaft, the body is swelled out to give great lateral strength to the crankcase about the crankshaft, and permit of direct connection to the engine bearers, while underneath there is a removable oil sump. Access to the working parts is given by inspection doors, which are fitted to each cylinder, one on either side of the crankcase. Cylinder liners of thin steel are inserted into the upper part of the casing, and are supported both at the top face and by a lower ring, which incloses the cooling water space

It will be seen that the cylinder head and valve gear form a separate unit, which is readily detachable. For each cylinder there are two exhaust and two induction valves which are operated through rocker levers by short push rods. As shown in the left-hand cylinder section, twin spark plugs are fitted in the crown of the cylinder head and are well cooled. The same illustration shows the end gearcase inclosing the gear drive from the crankshaft. The camshaft, it will be seen, is driven by a series of intermediate gears, which in turn are usually employed to drive various accessories mounted on the end case. This casing, with its attachments, is so designed that it can be removed from the engine in a few minutes while each accessory can, when required, be quickly detached. The various auxiliary fittings referred to, include, besides the two magnetos, the lubricating oil pressure and suction pumps, the circulating water and fuel pumps, as well as a gas distributor, and gun gear, when the engine is designed for use in a military machine. At the bottom of the gearcase there are duplex lubricating oil filters on both the pressure and suction sides of the oil system. The filters are provided with change-over valves, so that either can be cleaned while the engine is running.

Brief reference may be made to the lubricating system. Oil is delivered under pressure to the main bearings, and passes by means of drilled passages to the big ends, after which it is taken up to the piston pins through tubular connections, which are strapped to the webs of the steel connecting rods. A hollow piston pin, with closed ends, is used. The piston is made of forged and machined aluminum, and is fitted with three piston rings and one scraper ring. All of the wheels have ground teeth, and ample lubrication is provided by the oil, which returns from the pressure-fed camshaft bearings.

The engine described was fitted with a 97 millimeter Zenith twin carburetor, which works together with an induction system, that has been evolved as the result of considerable experimental work. The test results given below apply to the engine fitted with this carburetor, but a superior performance which approximates more closely to the standard type of engine

is given when a 120 millimeter carburetor is fitted.

TEST RESULTS

Speed, load and power			Fuel-consumption	
R.P.M.	Pounds loads	B.Hp.	Average fuel used per hr., gal.	Pounds per B.Hp. hour
1220	710	722	44.22	0.465
1220	795	808	51	0.48
1350	843	949	63.75	0.512

The BMW Va Aero-Engine.—This is a six-cylinder, water-cooled engine and represents an improved form of the BMW IV, with increased output, reliability and durability. In designing this engine special care was taken that it could be installed in any plane in place of the BMW IV, without difficulty. As in all other BMW aero-engines, the principle of the

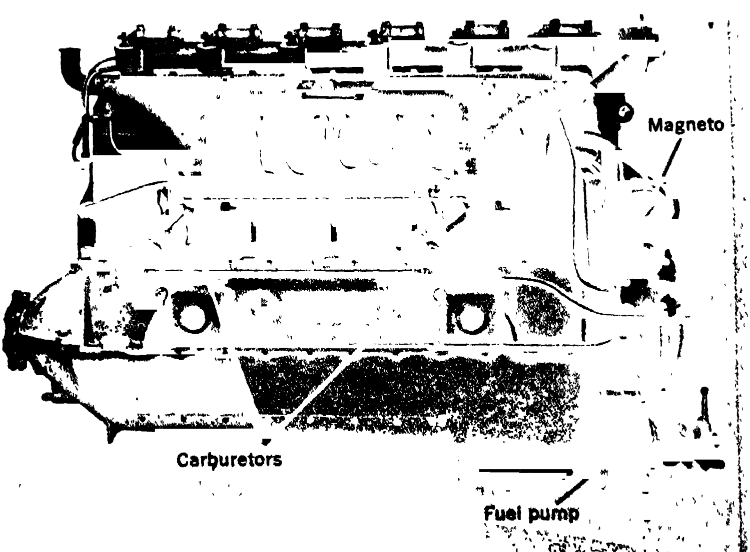


Fig. 716.—Carburetor Side of BMW Va (German) Six-Cylinder Aircraft Engine.

over-dimensioned, high compression altitude engine is applied to the BMW Va. The side view of the engine is shown at Fig. 716 and a rear or anti-propeller end view is given at Fig. 717. Special care was taken to produce a reliable crankshaft assembly. The crankshaft is therefore specially well dimensioned and has proved its absolute reliability in test runs of several hundred hours at an average continuous output of 350 horsepower. As a result of the dimensions of the crankshaft assembly, it is possible to run the BMW Va engine at the maximum output (now called the "highest permissible output") not only for a few minutes, as was the case with all

BMW engines up till now, but for an hour, if necessary. This fact was proved during the type test, which included five hours running at the highest permissible output, with a continuous run of four hours.

Instead of the usual thrust ball bearing, the BMW Va is fitted with a plain bearing for taking up the propeller thrust. This improvement has proved extremely advantageous and after several hundred hours of very heavy running on the test bed no signs of undue wear could be found

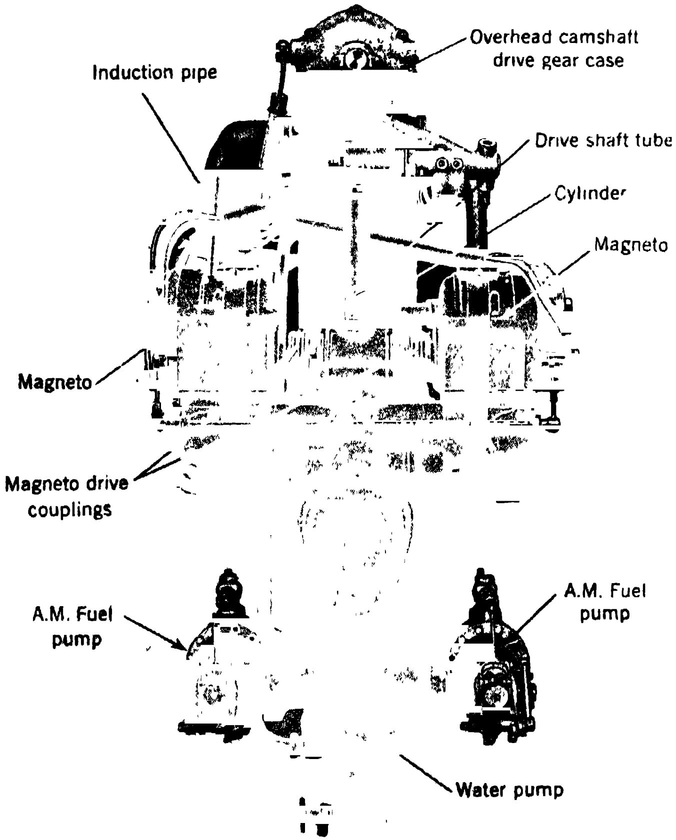


Fig. 717.—Anti-Propeller End View of BMW Va Six-Cylinder Engine Showing Magneto Drive, AM Fuel Pumps and Water Pump.

although the propeller thrust is much heavier on the test bed than when the engine is installed in the plane. The arrangement of the plain thrust bearing makes it possible to provide a flange propeller boss, which has many great advantages in comparison to the conical bosses. For one thing, the boss can never seize, as is so often the case with conical bosses. For this engine, the specially designed BMW boss can be used. The boss

driving flange is shown at Fig. 716. Another advantage in comparison to the BMW IV engine is the cooling of the oil by means of the cold mixture. A special eccentric pump turns the oil in the sump in the lower part of the crankcase about twice in the minute and forces it through a jacket surrounding the induction pipes, between the carburetor and the engine, the oil transferring its heat to the cold mixture. For planes which are intended for use in specially hot regions, an additional oil cooler can be fitted in the oil piping, behind the heating jackets on the intake pipes.

The new centrifugal drum oil cleaner greatly increases the reliability of the engine, as all dirt and foreign matter is removed from the oil. This oil cleaner is fitted in the hollow magneto-bracket on the carburetor side of the engine and the drum can be taken out and cleaned by simply removing the cover, which is fixed by four screws. In view of the great reliability and durability of the BMW IV type of cylinders, the same type, with several small improvements, which experience has shown to be necessary or advisable, is used for the BMW Va. These slight improvements, taken as a whole, have led to an enormous improvement in the running period between overhauls. The BMW IV type of valve actuation has been adapted to the BMW Va, as the use of rockers and springs which are always accessible greatly simplifies the upkeep of the parts in question. For this reason, this system is just as popular as the totally enclosed type. Certain improvements have also been made in the fixture of the camshaft casing, so that the strain on the bolts is very small. At the same time, a further advantage is incorporated in this improvement as the cylinders are interchangeable, and the supporting surfaces for the camshaft casing can be ground to exactly the same height for all cylinders.

The vertical driving shaft for the valve gearing is made from one piece with the driving pinion, the gear for the auxiliary drives and the worm wheel for the distributor of the compressed air starter. This shaft runs in plain bearings. Any displacement of the driving gear is thus quite impossible and the use of plain bearings, necessary as a result of the shaft and the various gears being manufactured in one piece, results in a very much more exact and quiet running than is the case with roller bearings. The magneto drive has been greatly improved by the use of double ball bearings for the driving gears and of the Bosch elastic rubber couplings. At the same time, a new Bosch magneto type "G.F.6" is used. In this new magneto, the armature poles, the coils and the interrupter remain stationary, and only a light sleeve for conducting and interrupting the lines of force revolves. The momentum of the rotating parts is thus extremely small and the variations in the torque of the engine and the torsional vibrations of the crankshaft cause only very slight strains on the magneto drive, due to inertia forces. If one takes the fact into consideration that the torsional vibrations of the crankshaft are very small as a result of the ample dimensions of the same it is evident that these improvements in the magneto drive lead to a considerable increase in the reliability of the engine in general. An improvement was also made in the distributor for the compressed air starter, which, up till now, rotated continually with the engine and had to be lubricated. The new BMW distributor is connected to the drive only when it is under pressure, and

as soon as the compressed air is turned off after starting the engine, the distributor and its drive disengage automatically. Only Zenith carburetors are now used, principally because this type is so much in use in Europe. In case of troubles, skilled mechanics, who know the Zenith carburetors thoroughly, can be found at every flying ground and spares and replacement parts can also be procured, so that the adoption of this type of carburetor is a great advantage for all users of the BMW engines.

Thus, all the experience of the past few years and all the suggestions made, although in many cases not vital, but nevertheless important to a certain degree, are incorporated in this new engine.

SPECIFICATIONS BMW Va

No. of cylinders	6
Arrangement of same	in row
Bore	6.299″ (160 mm)
Stroke	7.482″ (190 mm)
Direction of rotation	anti-clockwise, facing propeller
Highest permissible no. of revs. when flying	1900 R.P.M.
Length overall, without AM pumps, with BMW boss	65.67″ (1668 mm)
Greatest breadth	25″ (635 mm)
Greatest height	44.61″ (1133 mm)
Weight of engine, ready for service, without propeller boss, compressed air starter and without water and oil in engine: with aluminum crankcase	698.7 lbs. (317 kilos)
Weight of BMW propeller boss	18.25 lbs. (8.28 kilos)
Weight of water in engine	22.05 lbs. (10 kilos)
Weight of oil in engine	13.23 lbs. (6 kilos)
Dimensions of packing case:	
Length	68.9″
Breadth	34.3″
Height	53.9″
Weight of packed engine	1180 lbs.

BMW VI Engine.—The BMW VI airplane engine shown at Figs. 718 and 719 is a water-cooled twelve-cylinder engine, with two cylinder batteries inclined at an angle of 60 degrees in the usual Vee form. The main constructional principles of this engine are the same as those of the famous BMW IIIa and BMW IV, which were such a remarkable success in the Civil Air Service. The principle of the oversized, high-compression engine, realized for the first time by the Bayerische Motoren Werke in their BMW IIIa engine, has also been applied to this type—to a much greater degree than in former types, in fact. The transmission parts are so dimensioned that it is possible to use the full maximum power at sea level for a short time, so that the greatest possible output is at the disposal of the pilot for the start. The surfaces of all bearings are so dimensioned that with a continuous output of 500 to 550 horsepower, which varies according to the ignition and vaporizing qualities of the fuel used, the greatest reliability and durability is insured. On the other hand, also, when the maximum output is used for a short time, there is no danger of overloading the bearings. These great advantages are attained, in the first place, by

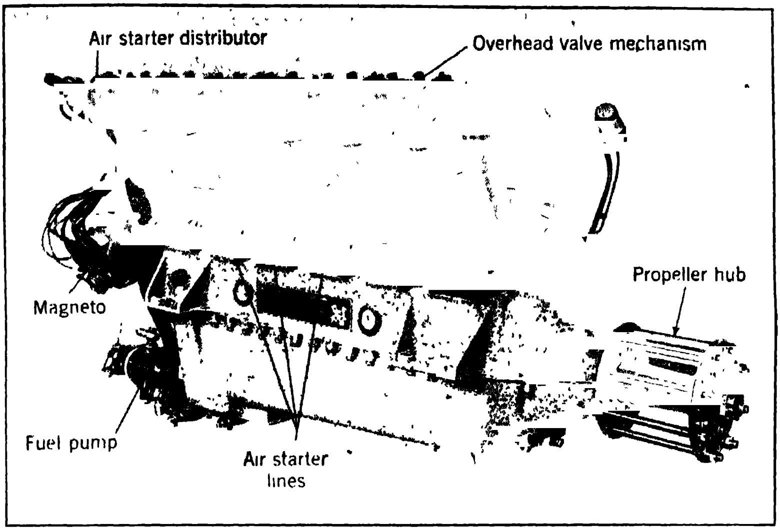


Fig. 718.—Side View of BMW VI Twelve-Cylinder Aircraft Motor, Typical of German "Vee" Engine Design.

providing roller bearings for the piston rods, special attention being paid to the development of the same. The BMW piston rod roller bearing has been so perfected that it can now be regarded as the most insensitive and inexpensive bearing in use. The engine may be obtained with or without reduction gear.

Each engine is supplied ready for service with two magnetos, circulation pump, oil pump, revolution indicator drive, atomizer and the piping on the engine itself. The following equipment is also supplied: propeller boss,

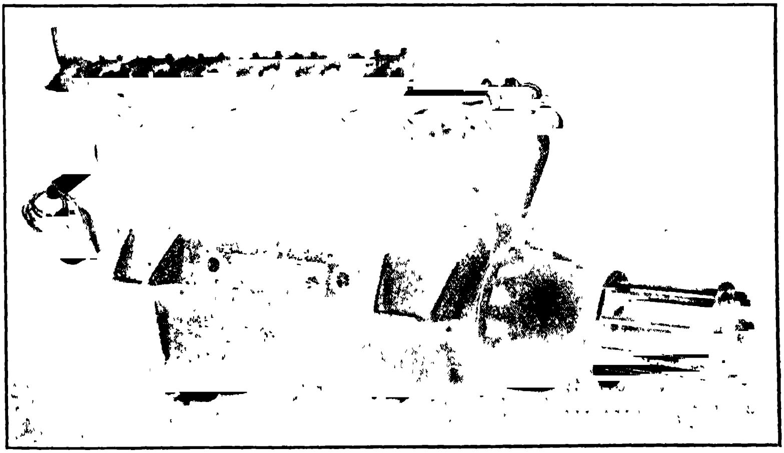


Fig. 719.—Side View of BMW VI with Farman Reduction Gear Installed.

one set of special tools, starter magneto (booster) with change-over switch, and fuel strainer.

It is possible to drive the following auxiliary mechanism, which can be supplied, if required, at an extra charge:—Dynamo for W.T., lighting and heating. AM fuel pumps. Compressed air starter. Hand turning gear or electric starter. Inertia starter. As fuel pumps, two AM pumps are supplied, which are so dimensioned that even if one pump is out of action the other still supplies the engine with sufficient fuel. As this pump is very popular on French and German aviation engines a sectional view of the pump is given at Fig. 720. The pumping element is a sylphon or metallic bellows member, guided by sleeve inside of which the return spring and operating plunger are housed. The plunger has a ring at the end that encircles the operating eccentric. The stroke can be varied by suitable mechanism.

CONSTRUCTIONAL DATA AND WEIGHTS

No. of cylinders		12
Bore		160 mm. (6.39″)
Stroke		190 mm. (7.48″)
Length overall (including AM pumps)	without reduction gear	1970 mm (77.6″)
	with reduction gear	2060 mm. (81.2″)
Greatest breadth	without reduction gear	844 mm. (33.3″)
	with reduction gear	844 mm. (33.3″)
Greatest height	without reduction gear	1057 mm. (41.4″)
	with reduction gear	1057 mm. (41.4″)

Weight of engine in running order, without water, oil, propeller boss and exhaust manifold:

Without reduction gear, aluminum	505 kilos	(1118 lbs.)
Without reduction gear, magnesium	460 "	(1015 ")
With reduction gear, aluminum	531 "	(1173 ")
With reduction gear, magnesium	488 "	(1075 ")
Weight of propeller boss, for engine with reduction gear	11.5 "	(25.3 ")
without reduction gear	12.6 "	(27.7 ")
Water contents of engine	19 "	(41.9 ")
Oil in sump	[illegible] "	(13.2 ")

Dimensions of packing case:	*Without red. gear*	*With red. gear*
Length	2 meters (78.6″)	2.1 meters (82.6″)
Breadth	1.06 " (41.7″)	1.06 " (41.7″)
Height	1.44 " (56.6″)	1.44 " (56.6″)
Gross weight of engine, packed in case:	840 kilos (1842 lbs.)	875 kilos (1925 lbs.)

		BMW VI 7.3 ε = 7.3 BMW Carb.	BMW VI 7.3 Z ε = 7.3 Zenith Carb.	BMW VI 6.3 ε = 6.3 BMW Carb.	BMW VI 5.5 ε = 5.5 BMW Carb.
MAXIMUM OUTPUT	**Hp.**	**700**	**800**	**640**	**600**
Revs. of crankshaft p.m.	"	1550	1700	1530	1500
Revs. of propeller p.m. with reduction gear	"	970	1060	955	940
Average continuous output allowable*)	"	500	500	500	500
Revs. of crankshaft p.m.	"	1390	1455	1410	1410
Revs. of propeller p.m. with reduction gear	"	870	910	882	882

WEIGHTS OF AUXILIARIES

Drive for W.T. dynamo	2.07 kilos	(4.55 lbs)
Compressed air pump set	1.13	(2.48 ")
AM pump set	8.93	(19.7 ")
Compressed air starter with 2 filled air flasks, sufficient for starting 20 times	31.65	(69.5 ")
Bristol gas starter, complete with fuel tank, but without fuel	25.50	(56.2 ")
Hand turning gear, BMW type:		
with hand starter magneto, incl. crank	9.3	(20.5 ")
without hand starter magneto, incl. crank	6.7	(14.75 ")
Electric Starter:		
Type "Farman," with battery and dynamo	38.5	(84.5 ")
Type "Eclipse," without battery and without dynamo	17.55	(38.6 ")
Battery for same	19.5	(43 ")
Inertia Starter:		
"Aeromarine," with hand drive	18.3	(40.4 ")
"Eclipse," with hand drive	11.75	(25.8 ")
"Eclipse," with hand and electric drive, without battery	15.5	(34.2 ")
battery for same	16	(35.2 ")

*) The average continuous ... be raised to 550 Hp ... duced to 450 H; ...ding to the quality of the fue... ed, the ha...ling of the ...e, the upkeep ... climate and similar factors

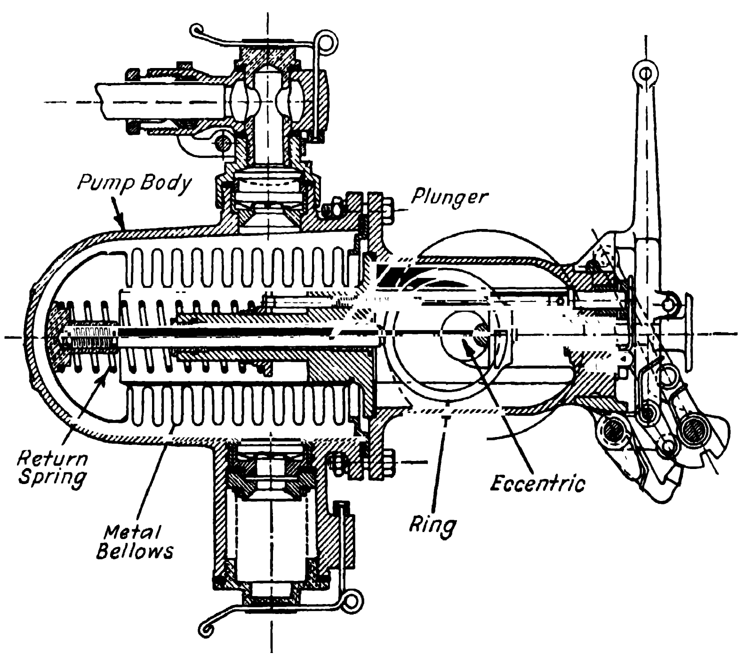


Fig. 720.—The A.M. Fuel Pump Sectional View Shows Metal Bellows of Sylphon Type Used with Various French and German Aircraft Engines to Supply Carburetors.

Lorraine W Type Engines.—The Societe Lorraine built two water-cooled motors having the W arrangement of cylinders. The twelve cylinder type shown at Fig. 721 is rated at 450 CV. It may be obtained either as a geared type using the Lorraine planetary reduction gear or with direct drive propeller. The direct drive type weighs 395 kilograms with all accessories, the geared type weighs 428 kilograms fully equipped. The cylinders are 120 millimeter bore and 180 millimeter stroke. The cylinders are assembled in groups of two though they are made separately and each two cylinders have a common water jacket of steel welded in place. Two valves are

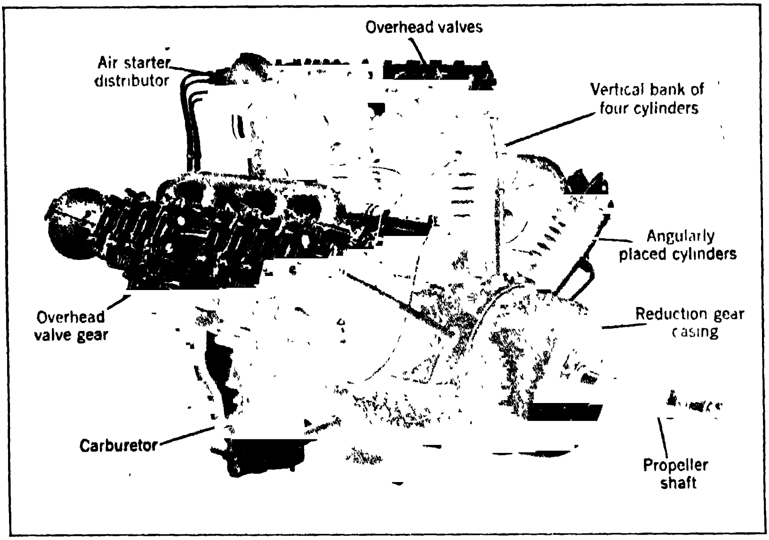


Fig. 721.—Propeller End View of Lorraine (French) Twelve-Cylinder W Type Aviation Engine Rated at 450 CV.

used per cylinder, each valve having three valve springs. The camshaft is the usual overhead type carried in aluminum housing as in the Liberty engine. Valve actuation is similar. Each rocker arm is carried by three bearings and cover plates give easy access to the housing interior. The motor crankcase of aluminum divided on the horizontal center line of the crankshaft, the three main bearings for the shaft being formed by upper and lower halves of the crankcase. The crankshaft is of alloy steel. The carburetor system includes two Zenith carburetors, one having a single mixing chamber and feeding only one set of four cylinders, the other is a double outlet form and feeds two banks of cylinders. Two AM type fuel pumps are placed at the rear of the magneto drive gears. Two twelve-cylinder magnetos are used for ignition. The oil circulation is by a triple oscillating plunger pump, the two outer plungers serving as suction members to draw oil from a separate tank and force it to the main bearings and to passages in the crankshaft. The oil also is fed to the camshaft housings to lubricate the cams and rocker arms and then returns to the crankcase. The center plunger of the pump is the scavenging member.

The motor is started by a carbureted air starter. The use of a reduction gear permits the engine to turn at 1,900 r.p.m. while the air propeller turns at 1,230 r.p.m.

An eighteen-cylinder W type motor is shown at Fig. 722. In this engine the cylinders are arranged in three banks of six, each cylinder being an individual forging of steel with a built on water jacket. The motor is rated at 650 CV., the cylinders being 120 millimeter bore and 180 millimeter stroke. This engine may also be obtained as a direct drive type which weighs 557 kilograms fully equipped while the geared type weighs 621 kilograms with accessories. In this engine four Zenith carburetors are

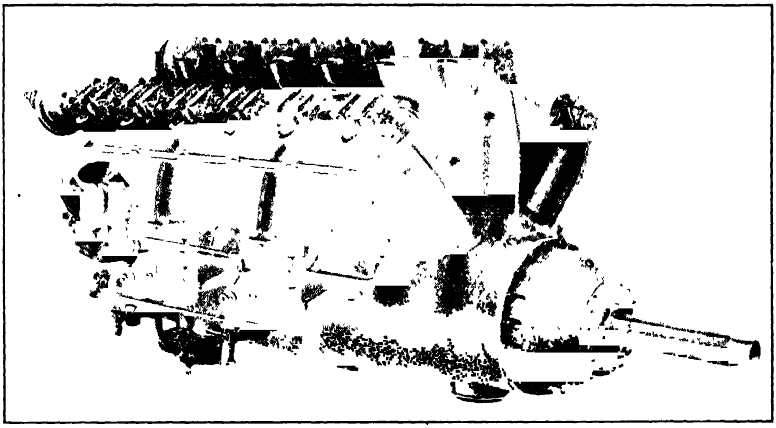


Fig. 722.—Propeller End View of Lorraine Eighteen-Cylinder W Type Water-Cooled Aviation Engine Rated at 650 CV.

used, two having single outlets, two having double outlets. They are the water jacket type. As this arrangement of carburetors provides six outlets, the manifolding is so arranged that each outlet feeds three cylinders only. Two magnetos are used, each having eighteen secondary distributor outlets. The engine is capable of speeds of 2,000 r.p.m. and in general details of construction it resembles the twelve-cylinder type. The crankshaft is a seven main bearing type and the bearings are held between upper and lower halves of the horizontally divided crankcase of aluminum alloy. The construction of the master connecting rods and link rods has been previously described in the section on connecting rods.

Panhard Sleeve Valve Type 12L Engine.—The only engine of which the writer has any knowledge that has received practical application in aircraft using the Knight sleeve valves instead of the usual poppet valves almost universally used is the Panhard Type 12L rated at 500 CV. The motor is the usual Vee type with two banks of six cylinders placed at an angle of 60 degrees. It is a four cycle type. The bore is 140 millimeters. The stroke is 170 millimeters. The compression pressure is determined by the ratio of 5.4 to 1. The valve actuation is by the usual small crankshafts mounted as auxiliaries to the main crankshaft which reciprocate the sleeves by small connecting rods as previously described in the chapter

on valve systems. Water cooling is by a centrifugal pump mounted at the anti-propeller end of the motor, as shown at Fig. 723, which also shows the magneto installation. The pump casing has one inlet and two outlet pipes. Lubrication is assured by gear pumps and is the usual pressure-scavenging combination used by most aviation engines.

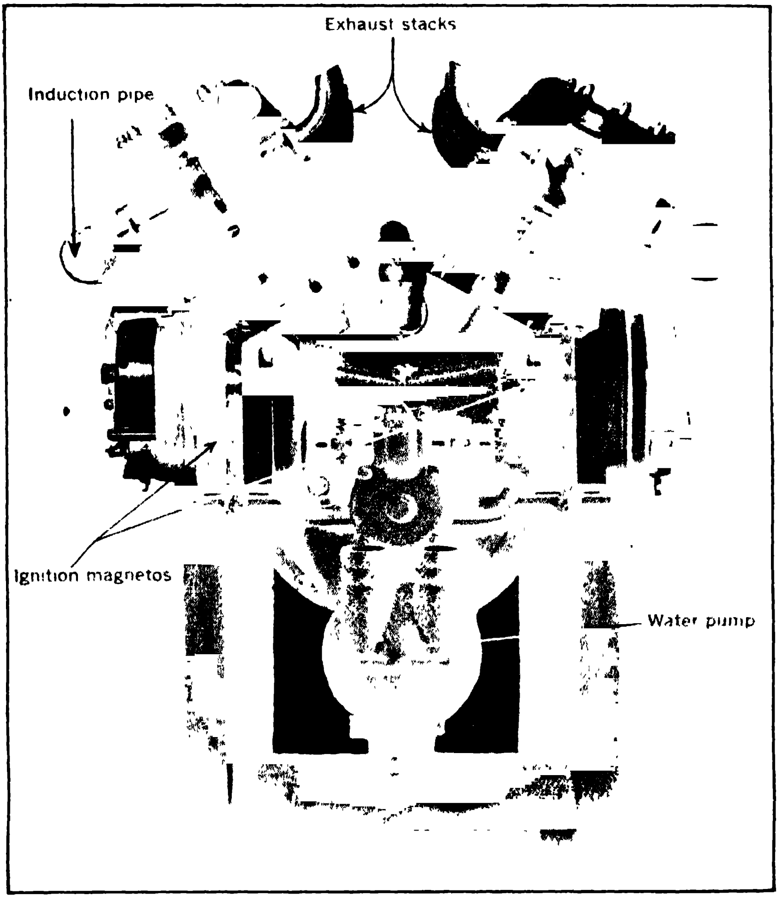


Fig. 723.—Accessory Drive End of Panhard (French) Twelve-Cylinder "Vee" Type Sleeve Valve Aviation Engine.

The carburetion is by special Panhard duplex carburetors, two being used, one for each bank and mounted on the outside of the bank instead of inside the Vee between the cylinders. Each of the mixing chambers feeds three cylinders by a straight manifold. Starting is accomplished by compressed air, a distributor being placed on the motor for the purpose of properly directing the air. The weight of the motor is given as 460 kilograms and it will deliver as high as 550 CV. (French horsepower). The motor is one meter 800 millimeters long including propeller hub. The width

of the motor is 880 millimeters and the height is the same as the width. A side view of the motor is given at Fig. 724. The cylinders are of steel, each cylinder having its own water jacket of sheet steel welded by the autogenous process. The cylinder heads are separate, as in all Knight motors and carry the sparkplugs and the air starter check valves.

The crankcases are made of special aluminum alloy known as Alpax and are divided on the horizontal center line of the crankshaft. The bearing supports are in both upper and lower crankcase members. The anti-propeller end of the crankcase is closed by a member carrying the bearing

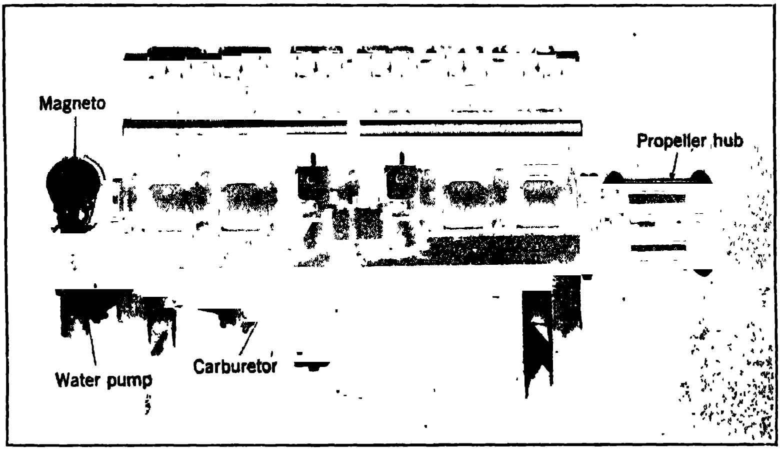


Fig. 724.—Side View of Panhard Sleeve Valve Motor Showing Carburetor Installation.

for the various accessory driveshafts as well as the pads for supporting the magnetos. A ball thrust bearing is mounted in the nose piece to resist propeller thrust in the usual manner. The sleeve valve reciprocating or eccentric shafts are supported by seven bearings and are driven by simple spur gearing. The sleeves are of steel, placed between the cylinders and pistons in the customary manner. The sleeves are provided with suitable ports registering with ports in the cylinders for the intake and exhaust of the gas. The crankshaft has six throws and is supported by seven bearings, two end main bearings and a bearing between each pair of cylinders. The connecting rods are of the fork and blade type. The pistons are of aluminum alloy and cast iron piston rings are used. The inside of the Vee between the cylinders is clear except for the exhaust outlets as shown in end view. As all of the sleeve valve actuating mechanism is carried inside the crankcase, the exterior of the engine is very clean. The dry weight of about two pounds per horsepower compares favorably with that of other engines of conventional form and design.

Rolls-Royce F Type Aero-Engine.—The Rolls-Royce F type aero-engine is of the twelve-cylinder water-cooled type having two rows of cylinders at 60 degrees, fitted with a spur drive reduction gear for the airscrew, magneto ignition and complete with engine supporting brackets. It is illustrated at Figs. 725 and 726. The engine can be supplied with

either .632 to 1 or .553 to 1 ratio reduction gear, also with either six to one or seven to one compression ratio pistons. With six to one compression pistons the engine will develop 490 brake horsepower at normal speed at ground level. If fitted with seven to one compression pistons, the engine will develop 480 brake horsepower at normal speed at ground level, and this power can be regained at an altitude of 3,000 feet by opening the throttle to full open position The engine is designated by four series numbers according to the gear ratio and ratio compression, the leading particulars of each series being as follows:

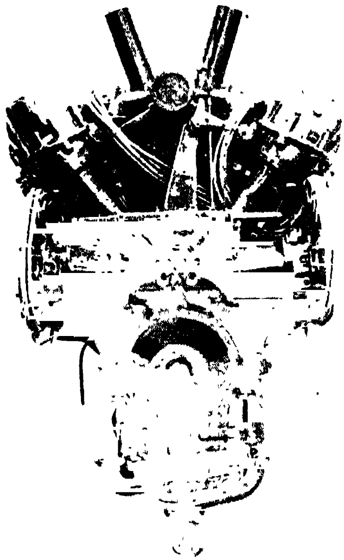
Series No.	F.XI A.	F.XI.B.	F.XII.A	F.XII B
No of cylinders	12	12	12	12
Bore	5″	5″	5″	5″
Stroke	5.5″	5.5″	5.5″	5.5″
Normal B.Hp	490	480	490	480
Normal speed (crankshaft)	2250	2250	2250	2250
Maximum speed	2500	2500	2500	2500
Normal speed of propeller	1421	1421	1244	1244
Reduction gear ratio	.632	.632	.552	.552
Compression ratio of engine	6:1	7:1	6:1	7:1
Fuel consumption in gallons per hour at normal power and speed	30	28.25	30	28.25
Oil consumption in pints per hour	5	5	5	5
Weight of engine, including carburetors, magnetos, engine feet, reduction gear, and airscrew hub, but excluding exhaust boxes, radiator, airscrew, oil, fuel and water in lbs	865	865	865	865

Cylinders.—The cylinders are in blocks of six, each block being mounted on the crankcase at an angle of 60 degrees with each other. They are of cast aluminum, provided with steel liners and renewable valve seats. The heads are integral with the cylinder blocks. Two inlet and two exhaust valves are provided per cylinder, operated by camshafts and rockers. The valves are made from special steel to withstand high temperature conditions, and operate in renewable guides. The camshafts and rocker mechanism are mounted on top of the cylinder heads, and are totally enclosed by means of a removable cylinder head cover. The whole of the valve mechanism is positively lubricated. The inlet and exhaust valves of each cylinder block are operated by one camshaft. The camshafts are machined from five per cent case-hardening nickel steel bar, the bearing surfaces and cam faces being hardened and ground. The valve rockers are five per cent case-hardening nickel steel forgings, machined all over and provided with hardened cam follower faces and hardened steel adjustable tappets.

Auxiliary Gear Drives.—The gears for driving the camshafts and all auxiliaries are driven from the rear end of the crankshaft, through the medium of a spring drive to elminate crankshaft torsional vibrations from all auxiliary drives. The gears are made from five per cent case-hardening nickel steel and worm wheels made from phosphor bronze, and all gears are fitted to shafts running on ball bearings and totally enclosed in a suit-

able casing. The camshafts are driven by means of inclined tubular driving shafts with bevel gears at the upper and lower ends. Out-of-alignment and expansion effects are allowed for by hardened serrated couplings. The driving shafts are supported in ball bearings, and the whole totally enclosed in tubular casings.

Pistons and Connecting Rods.—The pistons are made from special aluminum alloy forgings machined all over, and are of special design, which enables the heat to be dissipated in order to keep the temperature of the piston heads as low as possible. Four piston rings are provided, three



ROLLS ROYCE F TYPE AERO ENGINE

ROLLS ROYCE "F" TYPE AERO ENGINE

Fig. 725.—Rear View of Rolls-Royce "F" Type (English) Aero Engine at A. Front View of Engine Shown at B.

being arranged as compression rings above the gudgeon pin and one scraper ring below at the base of the piston skirt. The compression rings are prevented from rotation by means of stops. The gudgeon pins are of five per cent case-hardening nickel steel, hardened and ground. They are arranged to be a "floating" fit in the piston bosses, as well as in the connecting rod small end, axial movement being suitably limited.

The connecting rods are "H" section of the "Forked" type, made from three and one-half per cent nickel steel forgings, heat treated to give a high Brinell, and machined all over to reduce weight variations. A divided white metal lined steel block is bolted to the forked rod. The plain rod works upon the center proportion of the steel block, the latter having white metal bearing surface. The small ends of both rods are fitted with "floating" phosphor bronze bushes. All bearings are positively lubricated under pressure.

Crankshaft and Crankcase.—The six-throw crankshaft is machined from a nickel chrome steel forging, all the journals and crankpins being bored for lightness and to convey lubricating oil to all bearings and connecting rods. All crankpins and journals are accurately ground to close limits for size and trueness of diameter. The crankshaft is carried in seven bearings of ample proportions. The crankcase is of special aluminum alloy, and is made in two halves of box section suitably ribbed to give the necessary stiffness. The main bearings, consisting of divided mild steel shells, white metal lined, are held in the upper half crankcase by special caps which are secured by suitable bolts on each bearing. Facings are formed on either side of the caps which fit between corresponding facings formed on cheeks within the upper half crankcase. Transverse bolts pass through the crankcase and caps. This arrangement secures the rigidity of one in which the caps are integral with the lower half, while retaining the advantages of caps bolted only to the upper half.

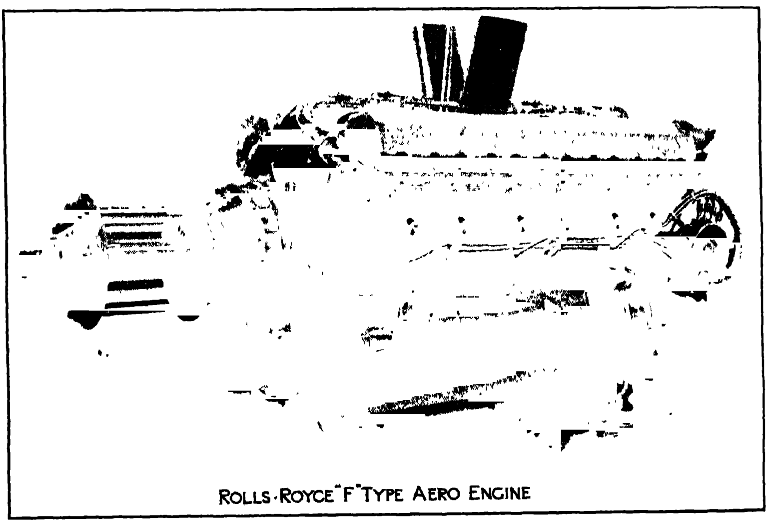


Fig. 726.—Side View of Rolls-Royce "F" Type Aero Engine with Geared Propeller Drive as Seen Looking from Propeller End.

Carburetion.—Two "Duplex" carburetors are provided of Rolls-Royce design and manufacture, fitted with automatic control by which the flow of petrol from the float chamber to the jet is automatically regulated to suit varying altitudes. Special compensating passages are provided in the carburetor, which maintain under all conditions the same pressure in the float chamber as in the throat, thereby neutralizing eddycurrent effects. These passages also enable the float chamber cover to be sealed thus reducing the risk of fuel leakage. The carburetors are mounted between the cylinder blocks and are provided with petrol drains at the lowest point, and one petrol inlet is provided for both carburetors. The induction pipes are designed to secure even distribution of the charge to the cylinders.

Magneto and Ignition System.—Two twelve-terminal high tension magnetos are fitted and are supported on the auxiliary gear case from which they are driven by means of serrated couplings. Incorporated in the latter is a device for enabling a fine and positive adjustment of the ignition timing to be effected. Two sparking plugs of approved make are fitted to each cylinder. The control mechanisms for throttle and mixture regulations are fitted on the engine, the magneto controls being inter-locked with the carburetor throttle controls. The connections between the engine and pilot's seat are not provided by Rolls-Royce, Ltd, being left to those responsible for the installation of the engine.

Reduction Gear.—A single spur gear reduction is fitted at the front end of the crankshaft, through which is transmitted the drive to the airscrew. The pinion is driven from the crankshaft through a short shaft, having teeth at the inner end to engage an internally toothed flange bolted to the crankshaft and at the outer end teeth engaging with teeth cut inside a part of the gear pinion. The use of this shaft prevents loads from the gear pinion coming on to the crankshaft. The gear wheels are carried on large size roller bearings, mounted in a substantial cast aluminum case. The airscrew hub is of three and one-half per cent nickel steel suitable for wooden type airscrew. The hub is provided with internal serrations and is mounted on similar serrations on the airscrew shaft.

Cooling and Lubrication.—A centrifugal water circulating pump of ample capacity is fitted below the auxiliary gear case and driven from same through serrated couplings arranged to take care of movement due to expansion or want of alignment. All water pipe connections consist of rubber joints to provide flexibility. The lubrication of the engine is on the "dry sump" system, the bulk of the oil being carried in a service tank separate from the engine. Two "scavenger" pumps and one "pressure" pump are carried at the rear end of the lower half crankcase—one "scavenger" pump being arranged to draw oil from the forward end of the crankcase, and the second one delivers the oil to the service tank. The "pressure" pump takes its supply from the service tank and delivers it to the main bearings and other parts under suitable pressure. Each "scavenger" pump is provided with a filter, each filter being contained in the oil pump casing. The main filter for the pressure pump is supplied as a separate unit. A compound relief valve regulates the pressure in the main system, and also adjusts the pressure of an auxiliary low pressure system which supplies oil to the camshaft bearings and their drive mechanism.

Engine Starting Gear.—Each engine is fitted with a hand starting gear mounted on the auxiliary gear drive casing, and arranged so that the starting handle can be used either side of the engine. Priming of the induction pipe is effected by the Rolls-Royce priming device, supplied with each engine, which enables a highly atomized mixture of gasoline and air to be injected into the induction system. This device is intended to be fitted to the pilot's seat and connected to the induction pipes by means of copper tube. This tube is not, however, supplied unless specially ordered. The airscrew hub is arranged to take a Hucks Starter Claw which can be supplied at an extra charge if specially ordered.

An arrangement for driving a revolution counter is mounted on the rear end of one of the camshafts, the connection being driven at one-quarter crankshaft speed. Provision is made in the auxiliary gear drive unit for driving the cams for operating the Constantinesco gun fire control gear. The auxiliary gear casing is also arranged to receive the plungers of the

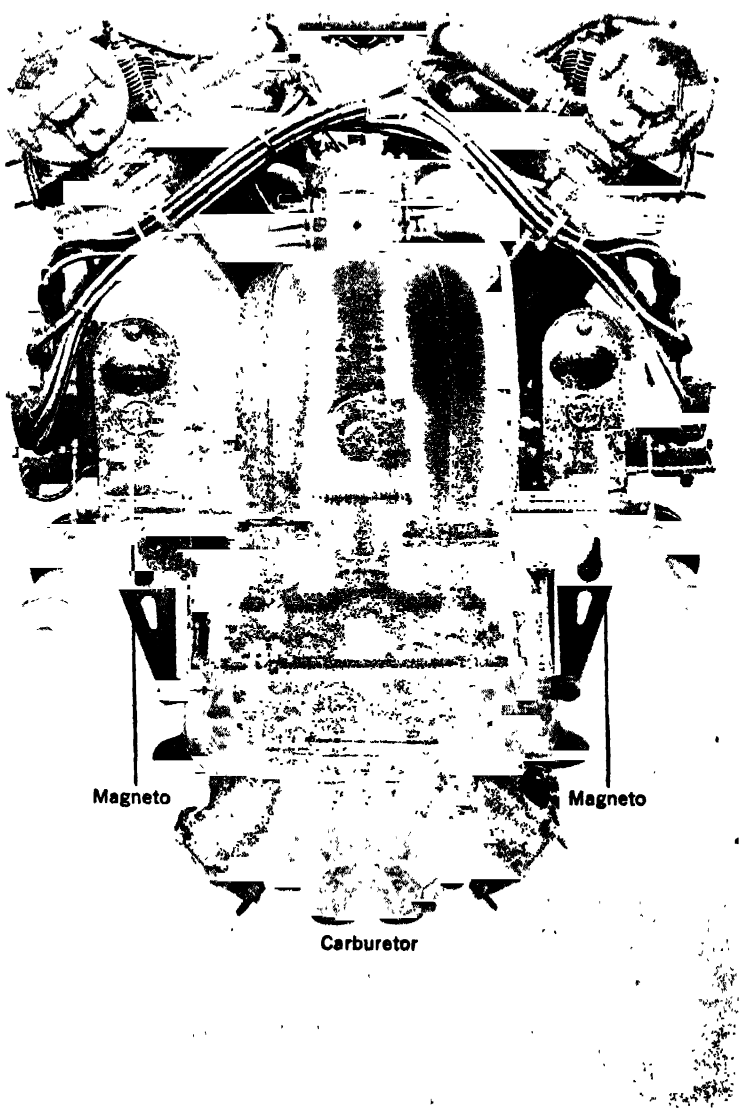


Fig. 727.—Rear View of Rolls-Royce (English) "Condor" III A Aircraft Motor Showing Carburetor and Ignition Magneto Installation.

gun control gear. The cams can be supplied at an extra charge, if required, but we do not include the plungers of the control gear. Suitable flanges are provided with each engine, and exhaust manifolds can be supplied at an extra charge. The direction of rotation of the propeller is anti-clockwise as viewed from the propeller end of the engine. The engine can be used as either a "tractor" or "pusher" without alteration.

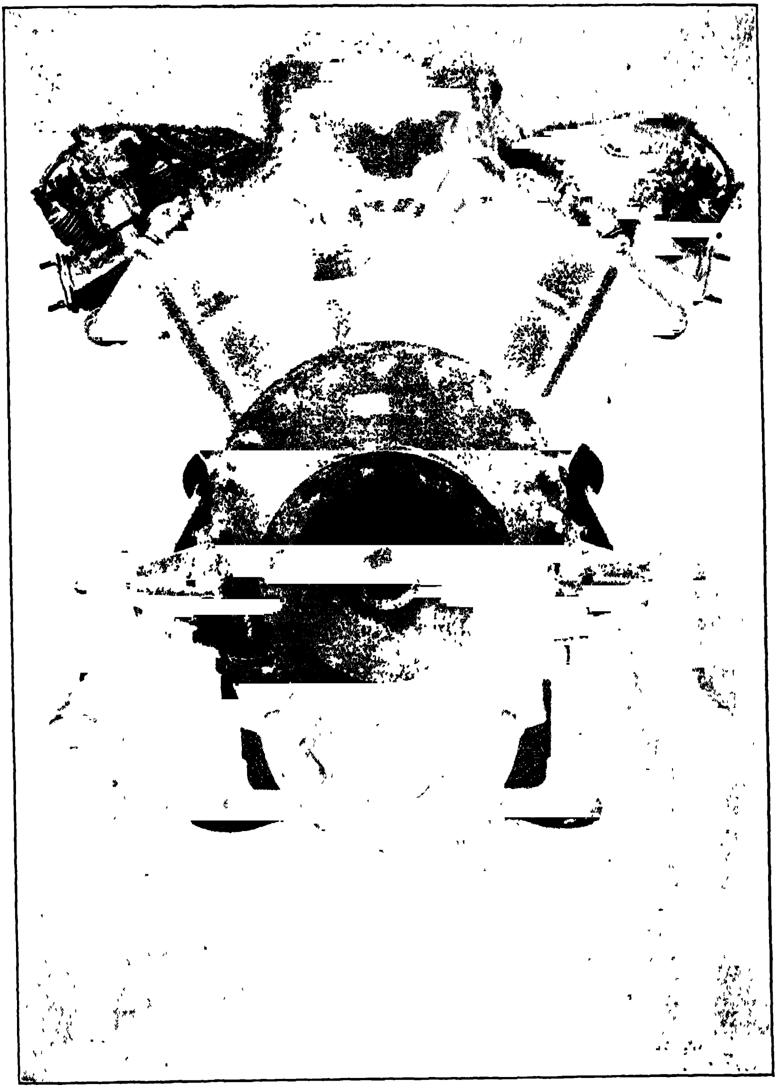


Fig. 728.—Front View of Rolls-Royce "Condor" III A Aircraft Motor Showing Reduction Gear Housing and Propeller Drive Flange.

A complete set of spanners suitable for carrying out adjustments and a light "overhaul" are supplied in a toolbox with each engine. A set of special spanners and tools such as are required for dismantling for complete "overhauls" and re-erection can be supplied at an extra charge All material used in the construction of these engines are produced in exact conformity with Rolls-Royce specifications, which are based on many years experience with alloy steels and nonferrous alloys. These specifications are within the scope of the standard specifications issued by the British Air Ministry. All mild and alloy steels are carefully tested in the raw state, every bar and billet being proved by heat treatment, fracture and Birnell test, to ensure that the raw material is correct to specification

Each individual crankshaft and propeller shaft forging is tested separately. Camshafts, connecting rods, etc., are tested in batches, one forging being selected out of each batch of a specified number and after heat treatment are required to pass the following tests:

(a) Tensile (static)
(b) Stanton (fatigue)
(c) Izod Single Impact (heat treatment test)

In the case of nonferrous metals, tensile test pieces are taken from every large casting and from every main cast.

Rolls-Royce "Condor III. A." Aero-Engine.—The Rolls-Royce "Condor" Aero-Engine is of the twelve-cylinder water-cooled "Vee" type, fitted with a spur drive reduction gear for the airscrew, magneto ignition and complete with engine supporting brackets. It is shown at Figs. 727 to 729 inclusive. The engine is of the high compression type and the carburetor is fitted with a stop to limit the opening of the throttle valve. This stop enables the correct position to be determined for the gate control on the aircraft, as the throttle should not be opened beyond the stop when the machine is operating at an altitude less than 3,000 feet.

The leading particulars of the engine are as follows:

Number of cylinders	12
Bore	5½"
Stroke	7½"
Normal B.Hp (at ground level)	665
Normal speed (Crankshaft)	1900 R.P.M.
Maximum speed (Crankshaft)	2100 R.P.M.
Normal speed (Propeller) with 477 reduction gear	907 R.P.M.
Fuel consumption at normal power and speed	41 gals. per hr.
Oil consumption	1.3 gals. per hr.
Weight of engine—including carburetors, magnetos, engine feet, distributor and pipes for power starter, etc., but excluding reduction gear, exhaust boxes, radiator, airscrew, oil, fuel and water	1182 lbs.
Weight of engine as above, but including reduction gear	1338 lbs.
Weight of engine complete with all the above, but without radiator, airscrew, water, oil and fuel	1364 lbs.

Cylinders.—The cylinders are separately mounted on the crankcase in two rows of six, at an angle of 60 degrees with each other. They are built-up of all-steel construction, being machined from .6 per cent carbon

steel forgings with the heads integral with the cylinder barrels. The water jackets are die-pressed steel, acetylene welded at the joints. The valve seatings are machined in the cylinder heads. Two inlet and two exhaust valves are provided per cylinder, operated by overhead camshafts and rockers. The valves seat direct in the part-spherical cylinder heads and their stems are consequently divergent. The valves are made from special high chromium steel forgings, working in phosphor bronze guides.

Camshaft Mechanism.—The camshafts are enclosed in steel tubular cases which are mounted on the top of the cylinders. Each camshaft is provided with six aluminum bearings which are in halves and bolted together, and two one-piece bearings, one at either end. To operate the divergent valves tappets are interposed between the cams and each rocker, the latter being arranged to swing in a plane coincident with or parallel to a plane in which its valve lies. The camshafts are machined from five per cent case-hardening nickel steel bar, and ground on the bearing surfaces and cam faces. The valve rockers are three and one-half per cent nickel steel forgings machined all over having hardened ends bearing on the tappets and hardened adjustable end pieces bearing on the valve stems.

Auxiliary Gear Drives.—The gears for driving the camshafts and all auxiliaries are driven from the rear end of the crankshaft, through the medium of a spring controlled friction-damped pinion, so eliminating from all auxiliary drives, crankshaft torsional vibrations and are totally enclosed in a suitable casing. All gears are made from five per cent case-hardening nickel steel, accurately fitted to shafts running on ball bearings. The camshafts are driven by means of inclined tubular driving shafts with bevel gear at the upper and lower ends. Out-of-alignment and expansion effects are allowed for by hardened serrated couplings. The driving shafts are supported in ball bearings and the whole totally enclosed in tubular casings.

Pistons and Connecting Rods.—The pistons are made from special aluminum alloy forgings machined all over, and are of special design which enables the heat to be dissipated in order to keep the temperature of the piston heads as low as possible. Four piston rings are provided, three being arranged as compression rings above the gudgeon pin and one scraper ring below at the base of the piston skirt. The compression rings are prevented from rotation by means of stops. The gudgeon pins are of five per cent case-hardening nickel steel, hardened and ground. They are arranged to be a "floating" fit in the piston bosses, as well as in the connecting rod small end, axial movement being suitably limited.

The connecting rods are "H" section of the "Forked" type, made from three and one-half per cent nickel steel forgings, heat treated to give a high Brinell, and machined all over to reduce weight variations. A divided white metal lined steel block is bolted to the forked rod. The other rod works upon the center portion of the steel block, the latter having white metal bearing surface. The small ends of both rods are fitted with "floating" phosphor bronze bushes. All bearings are positively lubricated under pressure.

Crankshaft and Crankcase.—The six-throw crankshaft is machined from a nickel chrome steel forging, all the journals and crankpins being bored for lightness and to convey lubricating oil to all bearings and connecting rods.

All crankpins and journals are accurately ground to close limits for size and trueness of diameter. The crankshaft is carried in seven bearings of ample proportions. The crankcase is of special aluminum alloy, and is made in two halves of box section suitably ribbed to give the necessary stiffness. The main bearings, consisting of divided mild steel shells, white metal lined, are held in the upper half crankcase by special "Duralumin" caps which are secured by long bolts adjacent to each bearing. Facings are formed on either side of the caps which fit between corresponding facings formed on cheeks within the lower half crankcase. Horizontal bolts pass through the lower half crankcase and the caps, holding these

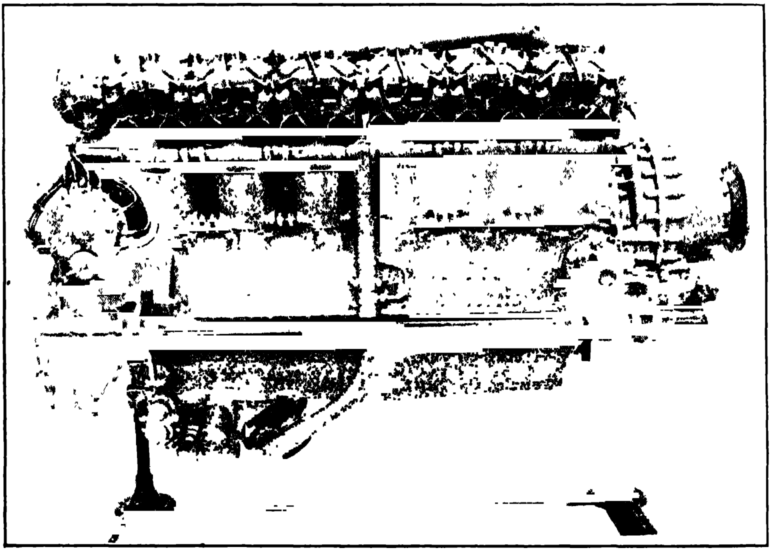


Fig. 729.—Side View of the Rolls-Royce "Condor" III A Aircraft Motor.

parts rigidly together. This arrangement secures the rigidity of one in which the caps are integral with the lower half, while retaining the advantages of caps bolted only to the upper half. A shaft driven from the timing gear is arranged to drive three oil pumps—two "Scavenger" 'and one "Pressure"—together with the water circulating pump, these pumps being bolted to the bottom of the lower half.

Reduction Gear.—A single spur gear reduction is fitted at the front end of the crankshaft, through which is transmitted the drive to the airscrew. The pinion is driven from the crankshaft through a short shaft, having teeth at the inner end to engage an internally toothed flange bolted to the crankshaft and at the outer end teeth engaging with teeth cut inside a part of the gear pinion. The use of this shaft prevents loads from the gear pinion coming on to the crankshaft. The gear wheels are carried on large size roller bearings, mounted in a substantial cast aluminum case. The airscrew shaft is of large diameter, made of nickel chrome steel, and is flanged at the front end to take a metal airscrew. A double thrust ball

bearing is contained in the gear casing to take thrust from the airscrew.

The airscrew shaft is provided with a flange to which the airscrew hub can be bolted. A hub suitable for a wooden airscrew can be supplied at an extra charge.

Carburetion System.—A twin carburetor is provided, each half supplying one side of the engine. It is of a special Rolls-Royce Claudel-Hobson type, fitted with rotating valve adjustments by which the flow of petrol from the float chamber to jet may be regulated from the pilot's seat to suit varying altitudes. Special compensating passages are provided in the carburetor, which maintain under all conditions the same pressure in the float chamber as in the throat, thereby neutralizing eddycurrent effects. These passages also enable the float chamber cover to be sealed thus reducing the risk of petrol leakage. The carburetor is mounted low down at the rear of the engine, facilitating the use of gravity feed for the petrol system. The carburetor is self draining through the air intakes. A large and convenient gasoline filter is supplied with the engine as a separate unit. The induction pipes are of large diameter, formed with easy bends and water jacketed adjacent to each carburetor.

Ignition, Cooling and Lubrication.—Two twelve-terminal high tension magnetos are fitted and are supported on the auxiliary gear case from which they are driven by means of serrated couplings. Incorporated in the latter is a device for enabling a fine and positive adjustment of the ignition timing to be effected. Two sparking plugs of approved make are fitted to each cylinder.

A centrifugal water circulating pump of ample capacity is fitted below the bottom half crankcase being driven from the auxiliary shaft through skew gears. All water pipe connections consist of special joints having rubber rings in compression where flexibility is required. In no case are rubber connections of the usual hose type employed.

The lubrication of the engine is on the "dry sump" system, the bulk of the oil being carried in a service tank separate from the engine. Two "scavenger" pumps and one "pressure" pump are arranged on the bottom of the lower half crankcase. The "scavenger" pumps draw oil from the crankcase, and deliver it to the service tank and the "pressure" pump takes its supply from the service tank and delivers it to the main bearings and other parts under suitable pressure. The "scavenger" oil pumps each have a coarse filter included in their casing, but the main filter for the "pressure" pump is supplied as a separate unit, easily taken to pieces for inspection without the use of tools. The pressure is regulated by means of a spring loaded relief valve.

Control Mechanism and other Auxiliaries.—The control mechanisms for throttle and mixture regulator are fitted on the engine, the magneto control being inter-connected with the throttle control. The connections between the engine and pilot's seat are not provided by Rolls-Royce, Ltd., being left to those responsible for the installation of the engine. An arrangement for driving a revolution counter is mounted on the timing gearcase, the conection being driven at one-quarter crankshaft speed.

Exhaust manifolds are fitted one on each side of the engine being constructed of light sheet steel pressings acetylene welded together.

The engine is fitted with a distributor and pipes to back pressure valves in each cylinder for use with a compressed gas starter. The latter is not supplied with the engine.

The direction of rotation of the propeller is clockwise as viewed from the propeller end of the engine. The engine can be used as either a "tractor" or "pusher" without alteration except to the top water pipes which require setting to suit. A complete set of spanners suitable for carrying out any adjustments to the engine together with a quantity of spare parts are supplied in a toolbox with each engine. A set of special spanners and tools such as are required for dismantling and erection are supplied at an extra cost.

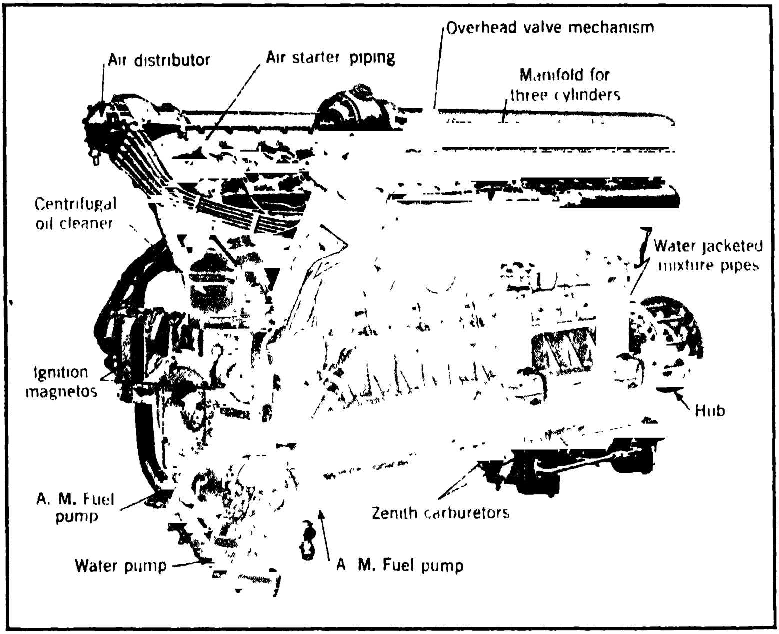


Fig. 730.—Three-Quarter View from Accessories Drive End of Renault (French) Twelve-Cylinder 550 CV Direct Drive Aero Motor.

New Series Renault Motors.—The Renault aviation motors are the result of a wide experience in the design and construction of powerplants for all types of military and civil aircraft. The new series range in power from 450 CV. to 750 CV. and are built in direct drive and geared types. The motors all have the same general characteristics and are of simple design to permit of light weight combined with reliability and endurance. The earlier Renault motors ranging from 300 to 480 CV. have given numerous proofs of their endurance and the new series should combine all the good features of the old line with the improvements of performance that refinement of detail due to greater operating experience always brings forth.

The description which follows applies specifically to the 550 CV.

illustrated at Figs. 730 and 731 which may be considered typical of the new Renault construction. The direct drive motor has twelve cylinders placed in two banks of six in the usual 60 degree Vee arrangement. The cylinders are 134 millimeters bore and 180 millimeters stroke, are of forged steel machined all over inside and out. The cylinder is provided with flanges at the top and near the base to which the water jacket is attached by autogenous welding. There are four valves per cylinder, seating directly into a flat top cylinder head, the combustion-chamber being of slightly greater diameter than the cylinder bore. The exhaust and intake pipes are made of steel stampings joined by the autogenous welding process.

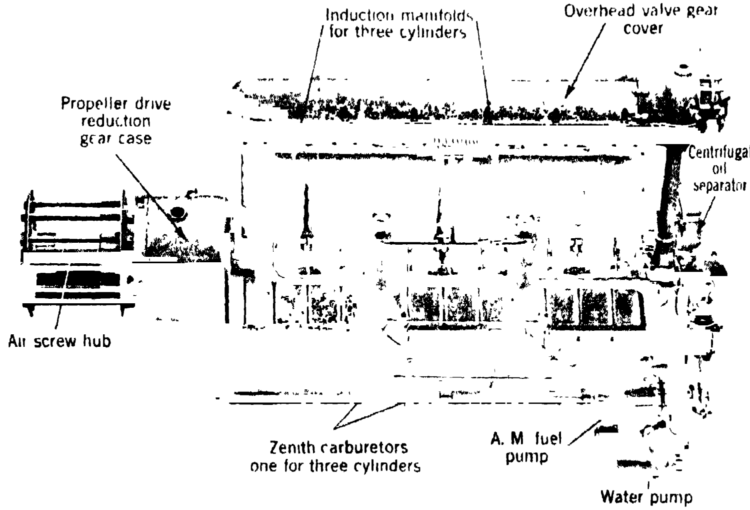


Fig. 731.—Direct Side View of Renault 570 CV Geared Drive Motor. Note Carburetor Installation.

Each cylinder is provided with two sparkplugs and a check valve for the air starter. The water jackets are corrugated and are proportioned to reduce the amount of water to a minimum without materially affecting the cooling. The valves are all the same size, are short and of substantial proportions and three springs are used on each valve. The pistons are of aluminum alloy, well ribbed for strength and are provided with six piston rings. The wristpins are hollow, of large diameter and are free in both the connecting rod end and the piston bosses, aluminum alloy buttons in the wristpin ends preventing scoring the cylinders.

The connecting rods are of the usual "H" section, forged of steel and having articulated or link rods attached in the conventional manner. The upper bearings are of phosphor bronze, the lower bearing of the master rod is of special white metal. The crankshaft is a seven bearing alloy steel forging mounted on plain bearings and carrying a deep groove ball bearing at the propeller hub end to take end thrust from either direction. The main bearings are formed between the upper and lower halves of the well ribbed aluminum crankcase. The lower crankcase member has a removable

cover to permit of inspection of the connecting-rod bearings and also carries an oil drain plug. A special casing placed at the rear of the motor carries the timing and accessory drive gears and the magneto supports. The camshafts are driven by bevel gears carried by driveshafts parallel to the center line of the cylinders. The camshaft carries one inlet cam and two exhaust cams for each cylinder. These cams actuate the valve stems through rocker arms carrying the clearance adjusting screw. The entire overhead valve mechanism is completely enclosed by casing covers which are easily removed to permit of inspecting the mechanism as shown at Fig. 732.

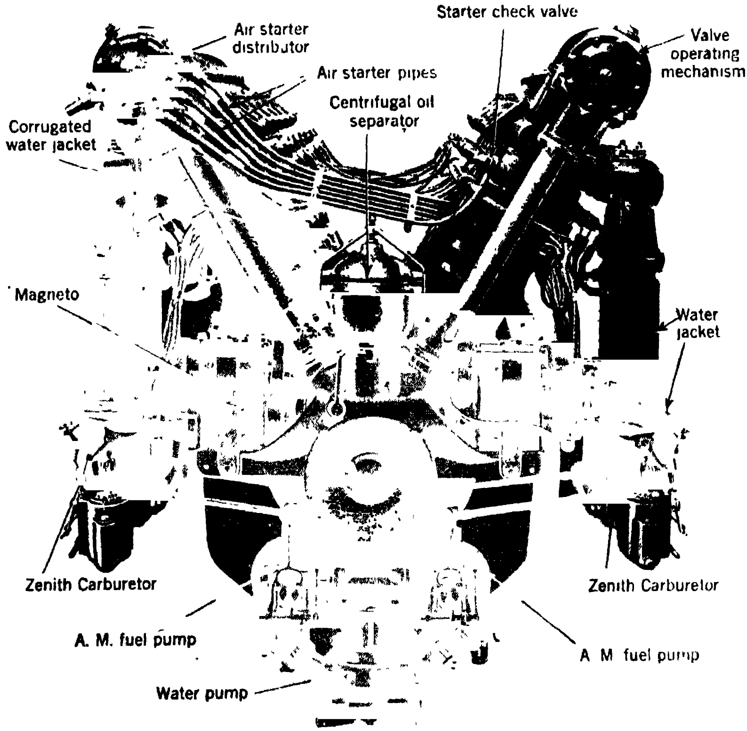


Fig. 732.—Accessory Drive End of Renault Aviation Motor Showing Centrifugal Oil Separator and Mounting of Air Starter Distributor.

Four carburetors are used, these being the Zenith 60J and are placed on the outside of the cylinder banks. Each single outlet carburetor serves three cylinders. The carburetors are the water jacketed type. Two magnetos are placed transversely at the anti-propeller end of the motor. Lubrication is by double gear pump, the lower one being the pressure or feed pump; the upper serving as a scavenging pump. A centrifugal separator is interposed in the lubrication system to remove all foreign particles, such as carbon, metal chips or core sand from the oil, which is thus maintained

clean at all times. Cooling is by centrifugal pump having two outlets, one for each bank of cylinders. Fuel feed is by AM fuel pumps, driven directly from the motor and placed below the magneto supports as shown at Fig. 732. The 550 CV. motor weighs 475 kilograms in the direct drive form and with the normal compression ratio of 5.6 to 1 will deliver that power at 1,800 r.p.m., and 620 CV. at 2,000 r.p.m. The other Renault motors differ in dimensions but the main features of construction are the same. The reduction gear is of the simple spur gear and pinion type, the propeller driveshaft being mounted above the crankshaft center line and bearings of the anti-friction type being employed to support the reduced speed shaft.

Salmson Water-Cooled Radial Engines—The CM9 engine was registered in July, 1923, at the nominal power of 260 horsepower for 1,650 r.p.m. It was especially designed to supersede the war model CUZ9, but developing a higher power with even more reliability. The CM9 260 horsepower was fitted to the Farman machine F90, piloted by Bossoutrot, on the 21st July, 1923, in the return flight between Paris and Lyons and won the Zenith Cup by having the minimum fuel consumption per carried kilogram. In September of the same year it was fitted to the four engine Farman Goliath, piloted by Bossoutrot and Drouhin, which finished in the "Grand Prix des Avions de Transport." In 1924, the CM9 260 horsepower accomplished successfully a reliability test of 300 hours at the official laboratory of Chalais-Meudon. On the 25th September, 1926 in the "Rallye Aerien National d'Auvergne" the pilot Codos on a twin-engine Farman Goliath, with CM9 engines, finished first in front of 34 competitors, averaging a commercial speed of 131 kilometers per hour for the 810 kilometers of the circuit and with 21 persons on board.

The CM9 260 horsepower has been adopted by important French aerial transport companies for its real qualities of solidity and reliability. Numerous models are fitted at present to the Berline Spad, the commercial three-engine Caudron machine and the twin-engine Farman Goliath, insuring daily an ever growing traffic on the principal lines of the Air Union and C.I D.N.A. Companies. Selected also by the French War and Navy Ministries for the heavy military machines, the CM9 260 horsepower is utilized by several squadrons of bombers. All the principal parts of the CM9 260 horsepower such as pistons, connecting rods, valves, valve springs, rockers, etc. are interchangeable with the corresponding parts of the AB9 230 horsepower, AB18 460 horsepower, and the CM18 500 horsepower, thus allowing a very noteworthy standardization of these four engines.

The CM9 260 horsepower engine is of the static radial, water-cooled four-stroke type and is clearly shown in the illustrations at Fig. 733 which show the motor viewed from the propeller and anti-propeller ends respectively. The cylinders have a bore of 125 millimeters and a stroke of 170 millimeters, which gives a displacement of 18,765 cubic centimeters. The compression ratio is either 5 or 5 4 to 1 and the engine is supported by the rear crankcase. The engine develops its nominal power at 1,650 r.p.m. The engine is one meter long and one meter eighteen millimeters in diameter. In complete running order with magnetos, carburetor and propeller hub it weighs 250 kilograms. The engine revolves in a clockwise direction for an observer standing at the propeller end and looking at the propeller.

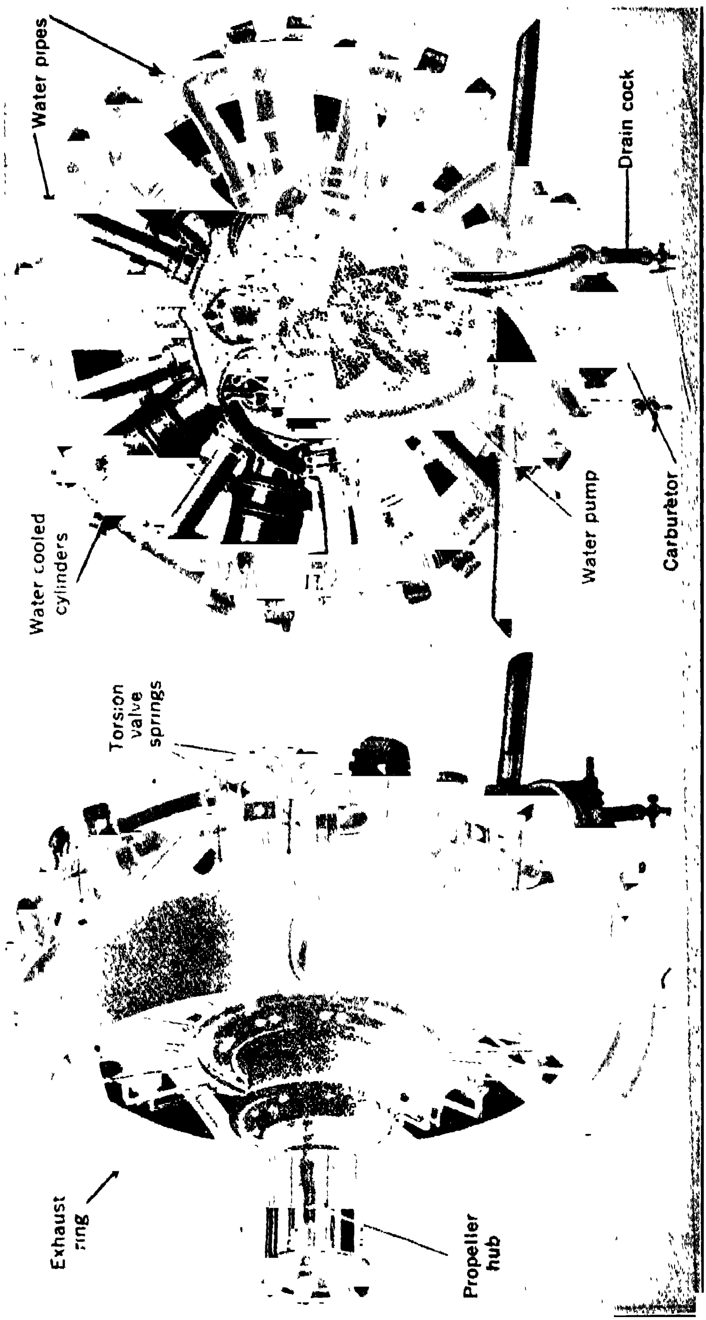


Fig. 733.—Front and Rear Views of Salmson (French) CM9, 260 Horsepower Radial Water-Cooled Engine. A Distinctive Type but Very Successful.

The engine may be used as a tractor or a pusher. The engine is fitted with a distributor to permit of air starting.

The nine steel cylinders, which have their water jackets welded on, are registered in the crankcases and kept in position by collar clamps. The master connecting rod, which is balanced and made of special steel, revolves on a white metal lined central bearing of large dimensions. The crankshaft of nickel-chrome steel carries two counterweights so arranged as to balance the whole group of connecting rods in all their positions and at all speeds. The distribution operated by a circular cam acts on the valves through roller tappets, rockers, and adjustable rods in the usual manner.

A single inlet pipe located in rear crankcase feeds each cylinder and receives the gases from a muffler connected to the carburetor which is fitted with an automatic altimetric correcter. Ignition is by two Salmson magnetos GG9 type, and two plugs per cylinder. Lubrication is effected by a pump returning to tank the oil scavenged from crankcase and is the usual dry sump pressure system

A circular manifold forming exhaust silencer and fitted with clearing pipes is supplied on request.

The CM18 engine was registered in August, 1923 at the nominal power of 500 horsepower for 1,650 r.p.m. but is able to develop 550 horsepower though being small in volume The CM18 engine 500 horsepower is fitted to the following planes.—Long Distance Scouting Breguet, 19A2 type; Long Distance Scouting Potez, 25A2 type; Long Distance Scouting Caudron, H31C1 type; Fighting Hanriot, H31C1 type; Fighting Bechereau, SB6C2 type; and the new commercial Hanriot machine H25.

Specially constructed with a view to safety and built only with the best materials, this engine accomplished successfully two official reliability trials of 150 hours each in fifteen periods of ten consecutive hours without the slightest trace of abnormal wear being noticeable on the main parts. The eighteen cylinders are in two radial groups of nine each as shown at Fig. 734 and are fitted by pairs to a bracket fixed by studs on the crankcase. Each pair can be removed and refitted independently of the others and the dismantling effected on the plane itself.

As in the AB18 460 horsepower engine, the air resistance is reduced to the minimum by the use of eighteen cylinders for a power of 500 horsepower and the disposition of the cylinders, one behind the other, in pairs, facilitates the entry into the air stream. All the principal parts of the CM18 engine 500 horsepower such as pistons, valves, valve springs, rockers, etc., are interchangeable with the corresponding parts of the types AB9 230 horsepower, CM9 260 horsepower, and AB18 460 horsepower, thus allowing a very noteworthy standardization of these four engines.

Napier "Lion" Aero Engine.—This is one of the best known of the British aircraft motors and has an enviable record of accomplishments to its credit and has received world wide distribution. It is made in a direct drive form illustrated at Fig. 735 and in the geared drive type shown at Figs. 736 A and B.

Cylinders are steel forgings machined all over. Water jackets of steel. Detachable aluminum cylinder head containing inlet and exhaust passages, valves and valve actuating mechanism. Pistons are of aluminum alloy,

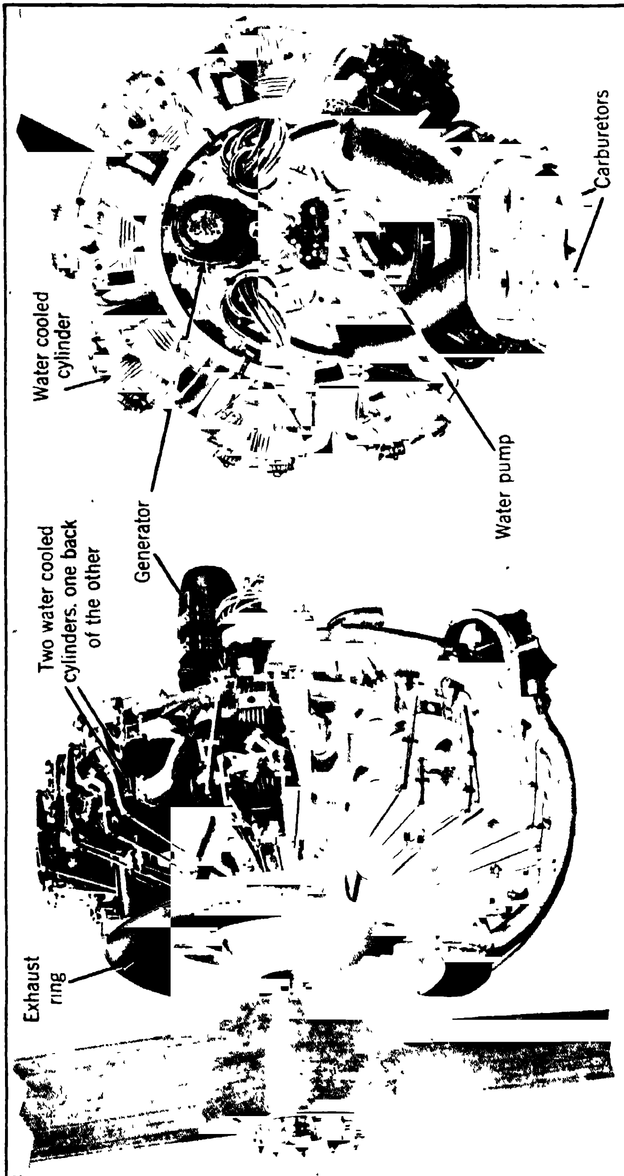


Fig. 734.—An Unusual Aircraft Motor Design. The Eighteen-Cylinder Salmson (French) CM18, 500 Horsepower Radial Water-Cooled Engine.

fitted with two compression and two scraper rings. Hollow gudgeon pins of large diameter, fixed in steel bushes. Two inlet and two exhaust valves are used per cylinder, each fitted with two coil springs and operated direct by overhead camshafts driven through bevel gearing by vertical shafts from the crankshaft. The whole of the valve mechanism is enclosed within a detachable aluminum case. Connecting rods are'machined from special high grade steel. The master rod, coupled to the pistons of the vertical block of cylinders, is formed with lugs on either side, to which are attached the short auxiliary rods for the pistons of the right and left groups of cylinders. The big ends are white metal lined, anchor pins and other parts work in bushes of ample size.

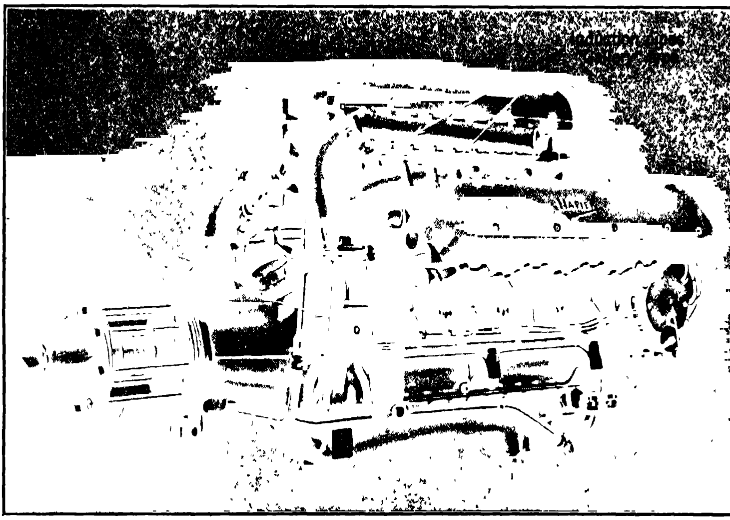


Fig. 735.—Napier "Lion" Direct Drive Aircraft Motor. A Distinctive and Popular British Design.

The crankshaft is machined from a solid steel forging. The four throws are in one plane and all journal bearings and crankpins are of large diameter and bored out. The shaft is carried in five substantial roller bearings and a large plain bearing at the forward end. Airscrew shaft and drive of the geared drive forms has a shaft rotating clockwise, when viewed from the airscrew end. It is carried on two roller bearings and fitted with a large double thrust ball bearing, to take the thrust of either a "Tractor" or "Pusher" airscrew. Reduction between airscrew and crankshaft is through high grade alloy steel spur gears. Shaft and its gear and cover can be withdrawn from crankcase. Crankcase and oil sump are of aluminum suitably stiffened at all necessary points and having arms on either side for attachment to the aircraft. The crankcase front end encloses the reduction gear for the airscrew shaft together with the shaft and bearings. The rear end cover contains the two scavenge oil pumps, the pressure oil pump and the drive for the camshafts, magnetos, water and oil pumps. Water

pump is a centrifugal type, mounted to rear end of engine and running at crankshaft speed. The spindle is fitted with a gland and a screwdown compression grease cup. Water is delivered through a separate outlet to each of the three cylinder blocks.

Oil pumps comprise two suction and one pressure type pump driven at half engine speed through gears. The suction pumps connected to the

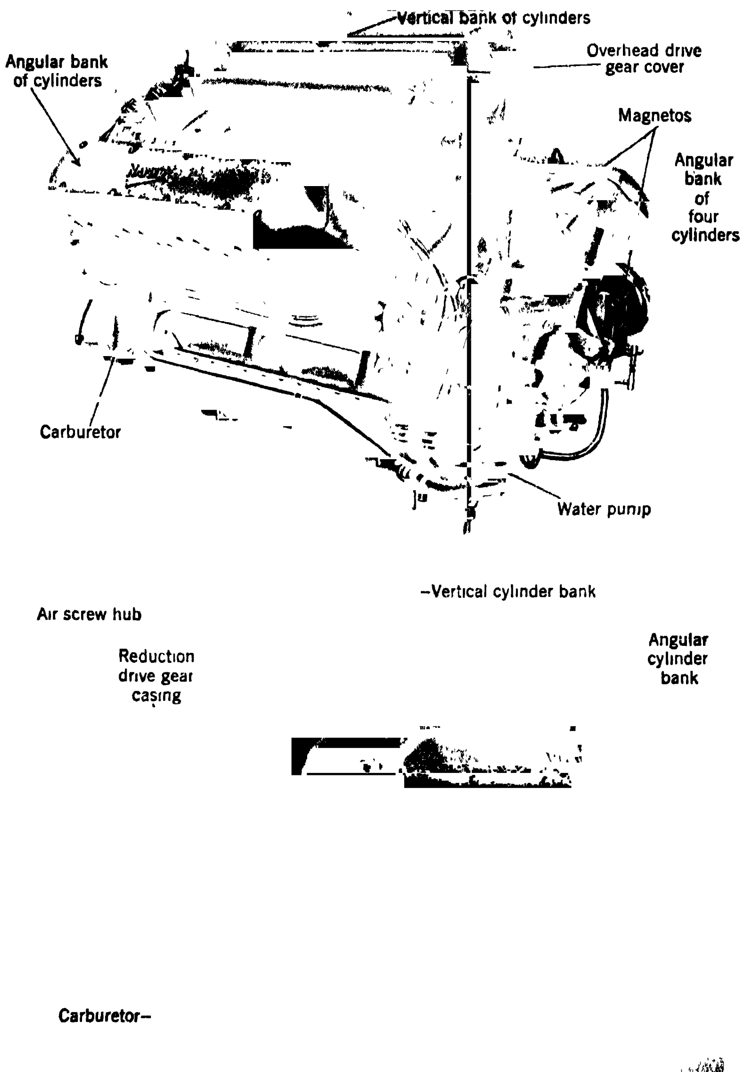


Fig. 736.—At Top, Accessories Drive End of the 450 Horsepower Napier "Lion" W Type Twelve-Cylinder Engine. View at B is the Propeller End of the 450 Horsepower Geared Drive Napier "Lion" Engine.

sump and the pressure pump takes oil from the supply tank through a suitable filter. Magnetos and ignition, two special twelve cylinder magnetos, rotating anti-clockwise, are mounted on platforms at the rear end of engine. Special distributors fitted to facilitate starting by hand. Metal braided ignition cables carried in aluminum troughs. Advance and retard links and levers interconnected. Carburetors, twin and single carburetors, Napier system are fitted. The bodies, which are of aluminum and stayed to the crankcase, are water jacketed. The gas inlet pipes to the induction port on the cylinder heads are of steel and are water jacketed. Altitude control cocks are fitted and are interconnected with throttle control. Lubrication is by pressure throughout to big ends, gudgeon pins, and bearings of camshaft. The cylinder walls and crankshaft bearings are lubricated by oil escaping from the big ends and gudgeon pins. The valve tappets and cams are lubricated by oil escaping from the camshaft bearings, which drains into the sump and is delivered thence to the supply tank by suction pumps. An adjustable pressure relief valve is incorporated in the system. The Napier petrol starter is provided, by means of which fuel is pumped into the cylinders and ignited by a hand starting magneto operated through the special distributors of engine magnetos. Hand turning gear, this is provided with a twelve to one reduction between the starting handle shaft and the crankshaft with throw-out gear to prevent damage by backfires. Engines can be supplied with water pipes arranged for either "Tractor" or "Pusher" aircraft Engines are delivered suitable for "Tractor" aircraft unless otherwise specified.

SPECIFICATIONS—NAPIER LION DIRECT DRIVE

NUMBER OF CYLINDERS—Twelve

ARRANGEMENT—Three blocks of four each, one vertical, two at 60°.

BORE—5½ ins.

STROKE—5⅛ ins.

HORSE POWER RATED—6.25 to 1 compression 525 @ 2,350 r.p.m., 5.8 to 1 compression 450 @ 2,000 r.p.m.

HORSE POWER AVERAGE—6.25 to 1 compression 540 @ 2,350 r.p.m., 560 @ 2,580 r.p.m.; 55.8 to 1 compression 473 @ 2,000 r.p.m., 502 @ 2,200 r.p.m.

DIRECTION OF ROTATION OF AIRSCREW SHAFT — Anti-clockwise, viewed from airscrew end

IGNITION—Two special magnetos giving dual ignition. Anti-clockwise rotation.

STARTER—Napier petrol priming system and hand turning gear.

WEIGHT OF ENGINE—Complete with airscrew boss, carburetors, induction pipes and hand turning gear, 915 lbs., subject to a plus tolerance of 10 lbs. If gun gear and petrol pump drives are also fitted, the weight will be approximately 925 lbs.

WEIGHT PER HORSE POWER:

6.25 to 1 compression, 1.74 lbs. on rated power.

5.8 to 1 compression, 2.03 lbs. on rated power.

6.25 to 1 compression, 1.63 lbs. on average power at maximum speed.

5.8 to 1 compression, 1.83 lbs. on average power at maximum speed.

LENGTH OVERALL TO CENTER OF AIRSCREW—4 ft. 9 in. approx.

WIDTH OVERALL—3 ft. 6 in. approx.

HEIGHT OVERALL—3 ft 3 in approx.

OIL CONSUMPTION—Approximately 20 pints per hour.

Napier "Cub" Aero Engine—This is a sixteen-cylinder X type of 1,000 horsepower that has many of the characteristics of the Napier "Lion" engines previously described. The cylinders are provided with corrugated steel water jackets and detachable aluminum camshaft casings and valve

actuating mechanism are bolted to the cylinder heads. Four valves are used per cylinder, each valve being controlled by two coil springs. The master connecting rod, coupled to the pistons in the port block of cylinders is formed with lugs on either side to which the auxiliary rods for the pistons of the other three groups of cylinders are secured. The four throw crankshaft revolves in five roller bearings and a large plain bearing a. the forward end. The crankcase is of aluminum, suitably ribbed for strength Cooling is by centrifugal water pump having four outlets, one for each bank of four cylinders. Two twin outlet carburetors with water jacketed inlet manifold feed pipes are used. Four eight-cylinder magnetos are used for ignition. The specifications of this engine, which is shown at Fig. 737, follow:

SPECIFICATIONS—NAPIER "CUB" ENGINE

NUMBER OF CYLINDERS—Sixteen

ARRANGEMENT—Four blocks of four each, 2 at 26¼° to vertical; two 26¼° below horizontal.

BORE—6¼ ins

STROKE—7½ ins

HORSEPOWER—Rated 1,000 hp Compression Ratio 5.3 to 1

DIRECTION OF ROTATION OF AIRSCREWSHAFT — Clockwise viewed from airscrew end

SPEED OF DITTO—Reduction ratio 1 to 2.04 of crankshaft.

IGNITION—Four special magnetos giving dual ignition Clockwise rotation

OIL CONSUMPTION—.035 lb maximum (.024 lbs. average) per b hp hour at full load

FUEL CONSUMPTION—.52 lb maximum (.49 lb average) per b hp hour at full load

STARTER—Pressure Gas System with distributing mechanism on engine

WEIGHT OF ENGINE—2,450 lbs approximately complete with airscrew boss, carburetors, induction pipes, magnetos, starting distributor gear and pipes

WEIGHT PER Hp—2.45 lbs

LENGTH OVERALL TO CENTER OF AIRSCREW—5 ft 11½ ins approximately

WIDTH OVERALL—4 ft 9 ins approximately

HEIGHT OVERALL—5 ft. 4¼ ins. approximately

Fiat AS3 Racing Engine—The Fiat engine with which Major Bernardi recently established the world's seaplane speed record of 318.62 m.p.h. at Venice, is a development of the one used in the Schneider cup race of 1926, and is designated AS3. It is shown at Fig. 743. The Fiat ASIII engine was designed by the Societa Anonima F.I.A.T., Turin, Italy, for the Macchi M52 racing seaplanes. It delivers 970 horsepower at 2,500 r.p.m. and is a development of the well known A20, 410 CV. shown at Fig. 738. It is of the twelve-cylinder 60 degree Vee water-cooled type. Cylinders have a 145 millimeter bore by 175 millimeter stroke. They are machined from steel forgings with separate welded steel jackets. Four overhead valves and two sparkplugs are used per cylinder. Valve seats and ports are welded into the cylinders. The compression ratio is 6.5. The valve gear consists of a single camshaft over each row operating the valves by means of rocker-arms. Camshaft and valve gear are totally enclosed in light alloy casings. Two concentric springs are provided per valve.

Pistons are magnesium alloy forgings. They have flat heads. Three rings are used above the gudgeon pin which floats in the piston. Connecting rods are articulated I section rods. Big ends are of bronze-backed white metal. Gudgeon pins are locked to the little ends. The crankshaft of nickel-chrome steel is of the six-throw seven-bearing type, with elliptic

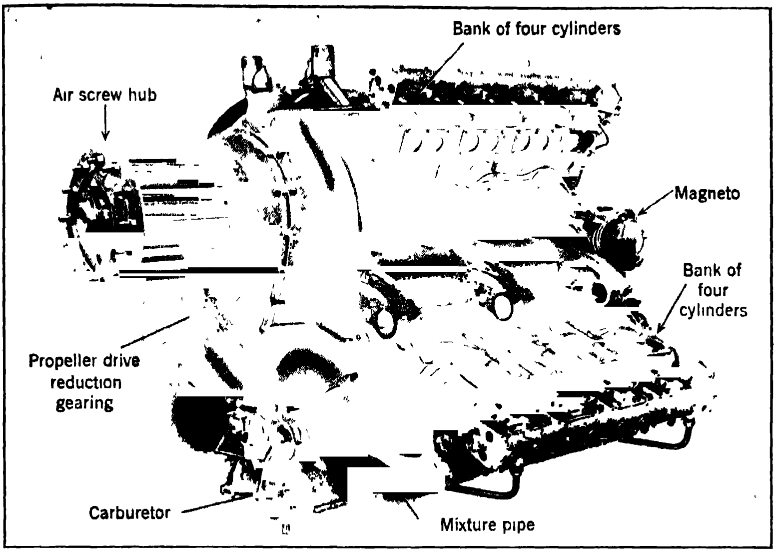


Fig. 737.—Three-Quarter View, Looking from Propeller End of the Sixteen-Cylinder X Type Napier "Cub" Engine Rated at 1,000 Horsepower.

profile webs. It runs in bronze-backed white metal bearings. The crank-case is a magnesium alloy casting. All crankshaft bearings except thrust and journal at the propeller end are carried entirely from upper half. The lower half carries two gear-type scavenger oil pumps and a centrifugal type water pump. The triple element oil pump is shown at Fig. 741 and the water pump at Fig. 742.

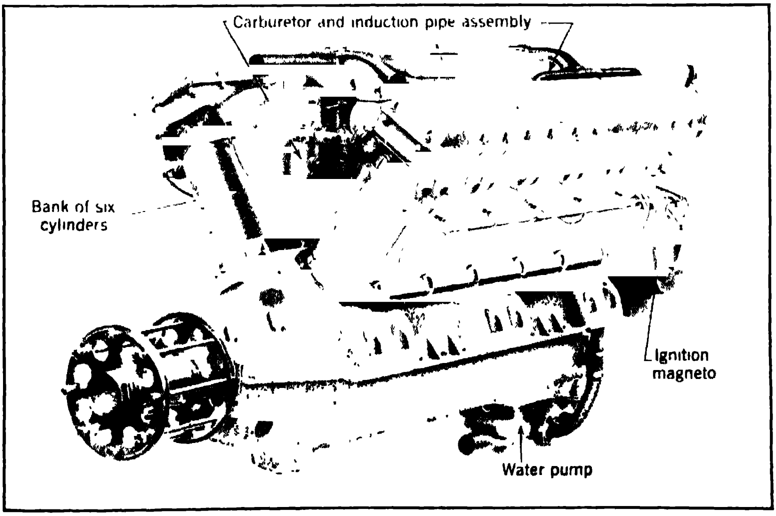


Fig. 738.—The Fiat Type A20, 410 CV Aero Motor is Typical of Italian Design and is a Very Practical and Successful Type.

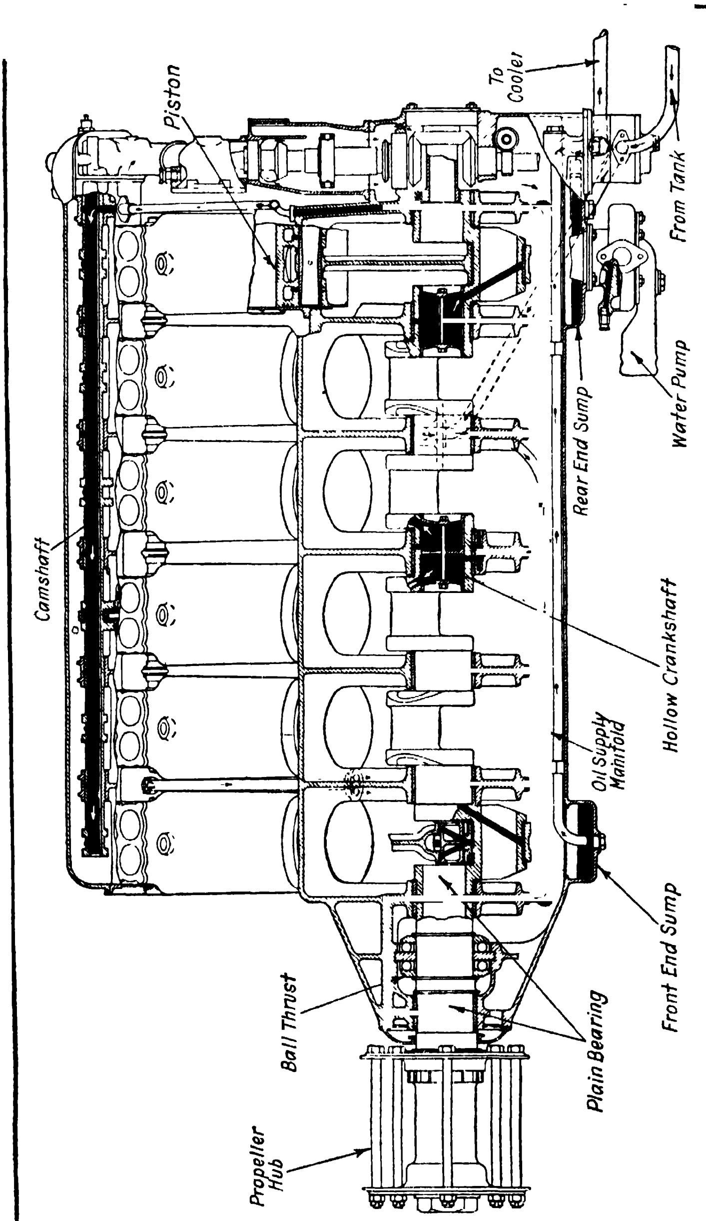


Fig. 739.—Lubrication System of Fiat Aviation Engines is Simple and Positive.

Auxiliary gears are all carried in a unit gear case attached to the rear end of the crankcase. One plain bevel pinion driven by tail-end crankshaft drives two vertical shafts. One passes downward driving the oil pressure pump, and through a train of spur gears the oil, scavenger and water pumps. An intermediate worm gear drives a horizontal shaft for a gasoline feed pump. The other vertical shaft first drives two horizontal shafts

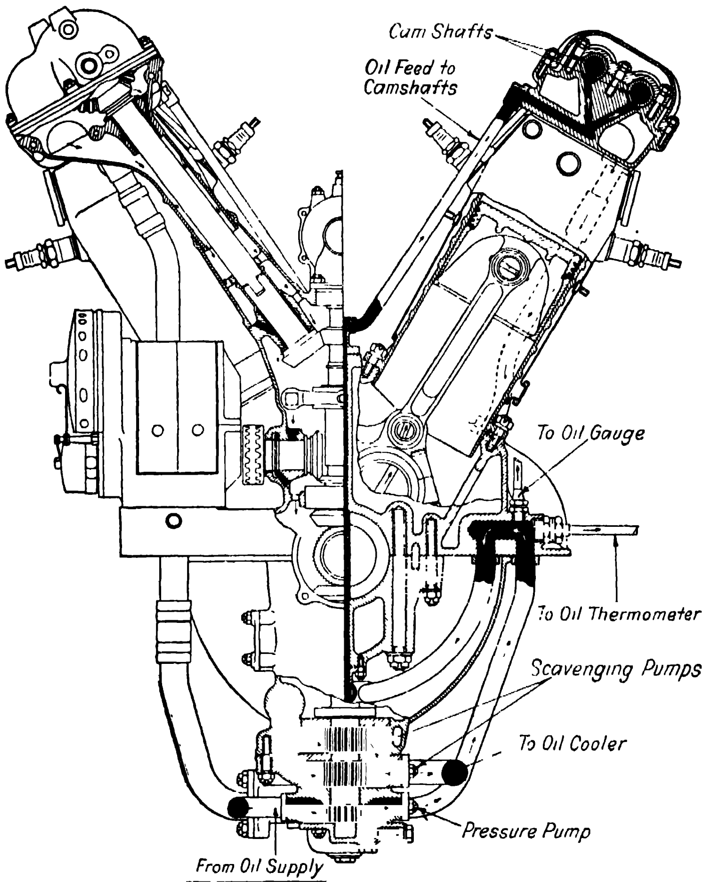


Fig. 740.—Transverse Sectional View of Fiat Aero Engine Showing Large Oil Passages and Three Section Gear Type Oil Circulating Pump.

for magnetos, and then two inclined shafts for the camshaft drive. Three special duplex Stromberg type carburetors are fitted between cylinders, each feeding four cylinders. Induction branches are water-jacketed. Lubrication is by pressure feed to each crankshaft bearing and thence through the shaft to the big ends. Oil is led from the rear crankshaft bearing to the camshaft. Oil from the camshaft returns over camshaft

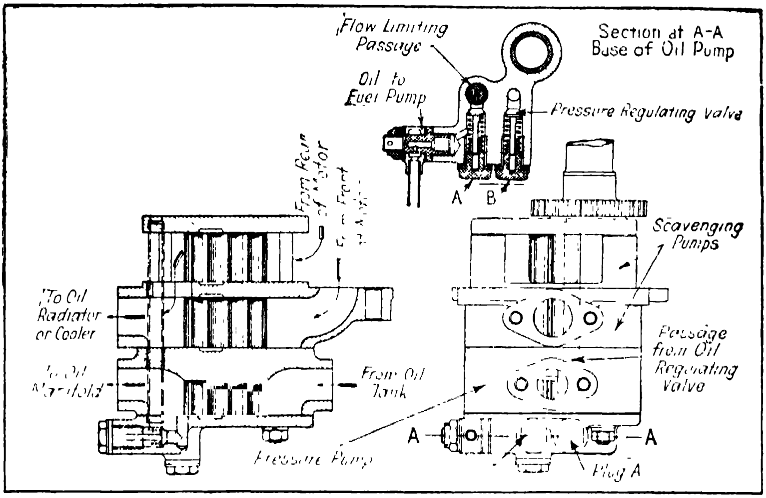


Fig. 741.—Diagrams Showing Construction of Fiat Triple Section Gear Oil Pump.

gears by way of the driveshaft casing to the crankcase. The method of oiling all Fiat engines is shown at Figs. 739 and 740 and is simple and direct. For starting, compressed air from a bottle at eight atmospheres is passed through a carbureting device to a gas distributor and thence to cylinders on firing strokes. A hand magneto fires the mixture in the cylinders. Overall dimensions: length 1 59 meters, (62.5 inches); width 0.72 meters,

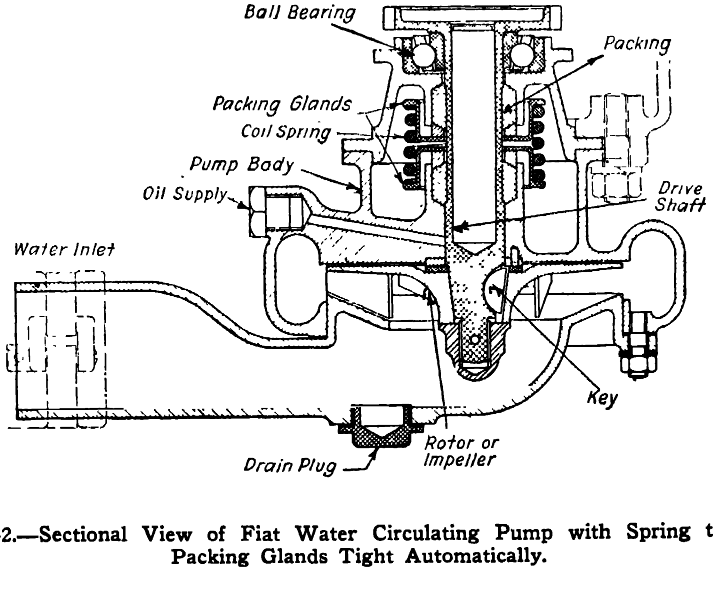


Fig. 742.—Sectional View of Fiat Water Circulating Pump with Spring to Keep Packing Glands Tight Automatically.

(28.3 inches); height 1.003 meters, (39.5 inches). The rated output is 970 horsepower at 2,500 r.p.m. The weight, dry, is 410 kilograms or 904 pounds which is equal to 0 423 kilograms or 0 93 pounds per horsepower.

Issotta-Fraschini Vee Type.—Much interest was aroused in aviation circles by the four continents flight of Commander Francesco de Pinedo of the Italian Navy, who flew in a Savoia-Marchetti seaplane from Sardinia, Italy, to the northern and western coast of Africa, across the southern

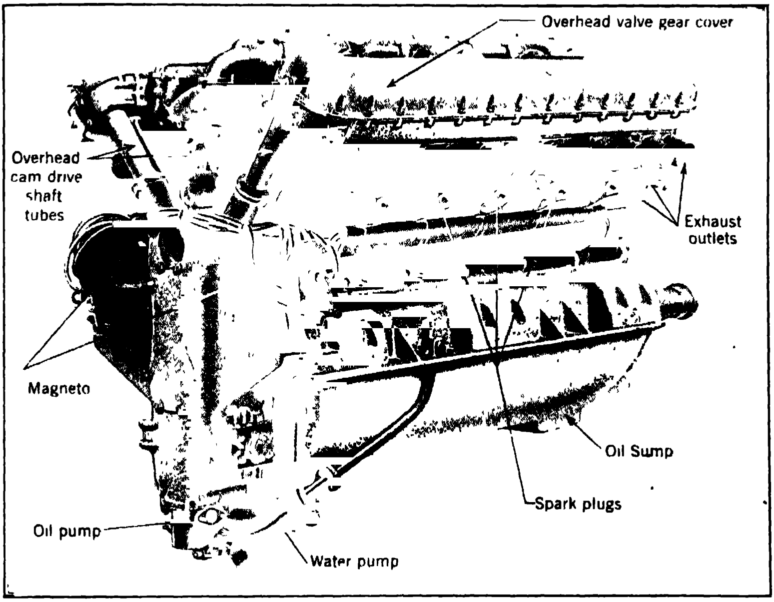


Fig. 743.—The Fiat Record-Breaking Racing Motor Type AS3 Delivers 1,000 CV and is a Twelve-Cylinder "Vee" Type.

Atlantic to Brazil and thence across unexplored regions of South America, the Carribean Sea and Gulf of Mexico to the United States. The plane flown by de Pinedo was equipped with two Issota-Fraschini "Asso 500" engines. These engines may be obtained either direct drive or with a reduction gear and in a special form for altitude flying. The piston dispacement is 1,691 cubic inches and with a compression ratio of 5.5 to 1 the power output is 506 horsepower at 1,800 r.p.m. The engine has twelve cylinders, arranged in two rows of six, set at an angle of 60 degrees as shown at Fig. 744. Its bore is 140 and its stroke 150 millimeters (5.52 by 5 91 inches), giving a total displacement of 27.7 liters or 1,691 cubic inches. With a compression ratio of 5.5 it has shown on the brake, 518 horsepower at 1,850 r.p.m., and 543 horsepower at 2,000 r.p.m.

Each cylinder is a separate steel forging and has the sheet metal water jacket welded to it. The head of the cylinders has flat top and bottom surfaces, and the four valves have their seats directly in the metal thereof. The cylinder head is a single aluminum casting to which the cylinders are bolted, making an extremely stiff assembly. Cooling water passes from

the cylinder jackets to the head jacket through holes in both parts, a special type of gasket being used to effect a water-tight joint. The reducing gear furnished has a reduction ratio of 2.17 to 1. In the special altitude type, while the general dimensions are the same, the compression ratio is increased to seven and a special arrangement is provided whereby the engine is automatically throttled at ground level, the degree of throttling decreasing progressively until at 15,000 feet altitude the throttle is fully opened. Engine power is therefore kept constant from the ground up to 15,000 feet altitude.

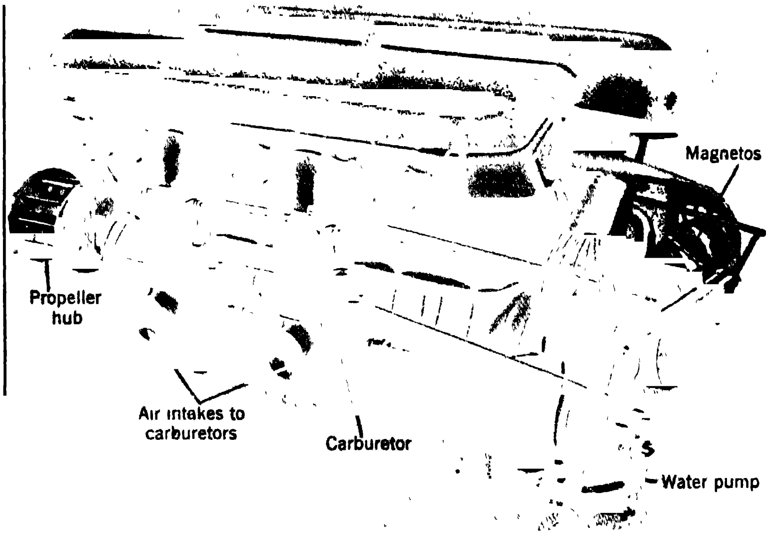


Fig. 744.—Issotta-Fraschini "Asso 500" Aviation Engine, Another Popular Italian Twelve-Cylinder "Vee" Design.

The inlet camshafts are driven through two inclined hollow shafts, and the bevel gears driving these shafts, as well as the spur gears through which the exhaust camshafts are driven from the former, are fastened to their respective shafts by means of splined joints comprising involute splines. The valves are held on their seats by two concentric coiled springs each, the two springs being wound right- and left-hand, respectively, whereby interference between them is said to be obviated.

The crankshaft is a chrome nickel steel forging, heat-treated, which combines high tensile strength with great surface hardness and consequent resistance to wear. It is supported in eight bearings, one on each side of each throw, and an additional bearing at the rear close to the propeller hub. Between the two rear bearings is located a double-direction ball thrust bearing which takes propeller thrust in both directions. All crankshaft bearings are of the conventional bronze-back, babbitt-lined type. The crankshaft is drilled through from end to end, for lightness and for the distribution of oil.

Pistons are metal mould castings of aluminum alloy as shown at Fig. 745, they are heat-treated (annealed) and are of very low weight. Each

piston carries four cast-iron piston rings, the lowermost of these being an oil scraper ring, from the groove of which the excess oil returns to the crankcase through a number of drill holes in the wall of the piston skirt. The piston pin floats. The pistons of each pair of cylinders having axes in the same transverse plane connect to the same crankpin, one directly through a master connecting rod, the other through a shorter rod articulated to the master rod. The articulated rod has a bearing on a hardened pin fastened into two drilled lugs formed on the master rod head. Both connecting rods are of I section, and the master rod is stiffened by two ribs.

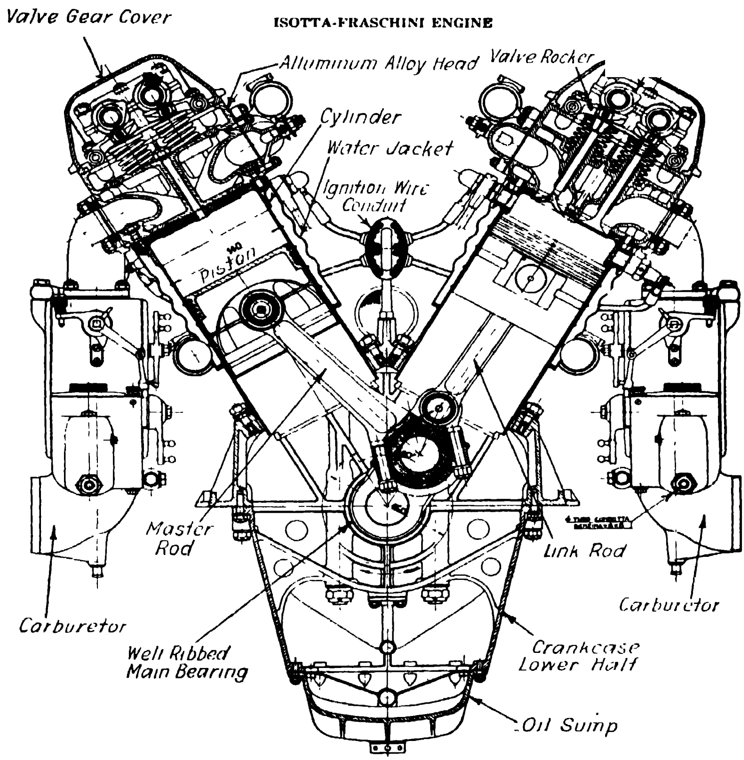


Fig. 745.—Transverse Sectional View of Issotta-Fraschini Aviation Engine Showing Cylinder and Head Construction Employed.

Four Zenith vertical-outlet, double-venturi type carburetors are fitted, these being specially made for this particular engine. They are located on opposite sides of the engine adjacent to the cylinder rows, and are readily accessible for inspection and can be easily dismounted, as they do not extend below the engine bearers. These carburetors are provided with hot water jackets through which water from the engine cooling system is

circulated by the centrifugal pumps, and the heat supply through the water jackets can be regulated at will by the pilot. They are also provided with an altitude corrector to counteract the tendency of the mixture to become over-rich with increasing levity of the atmosphere at high altitudes. Fuel is fed to the carburetors by two gasoline pumps mounted on an extension of the magneto bracket and driven from the engine. Ignition is by two

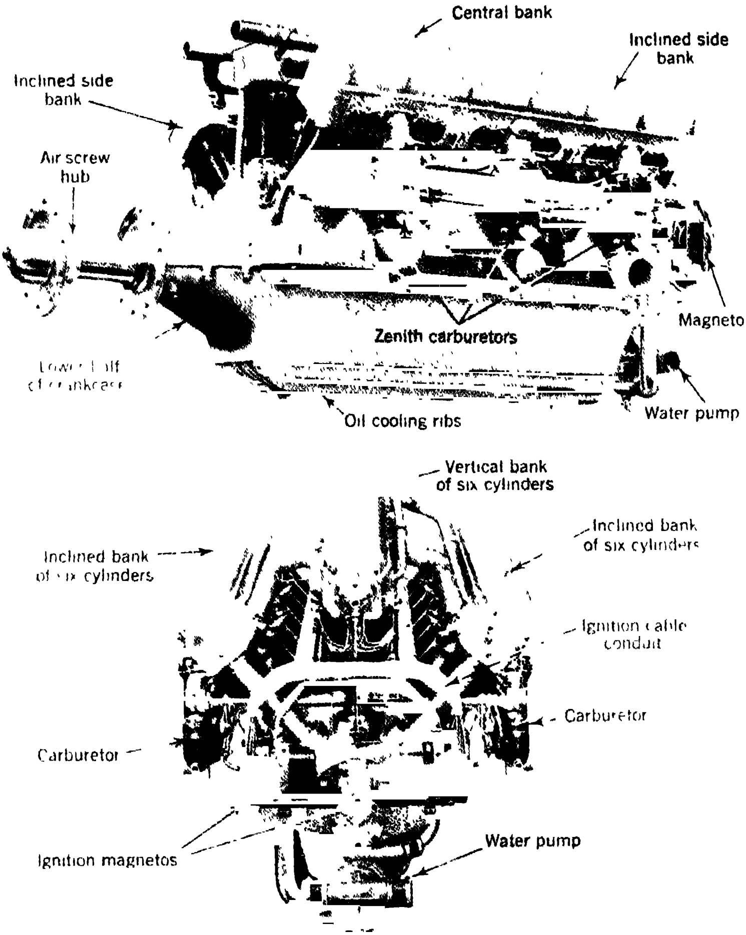


Fig. 745 A and B.—The Eighteen-Cylinder Isotta Fraschini ASSO 1000 W Type Water-Cooled Engine Has Three Banks of Six Cylinders Each.

twelve-cylinder magnetos, each cylinder being provided with two spark-plugs, and each plug connected by a cable to one of the magnetos. The magnetos are driven through flexible couplings of a type which allows of very close adjustment of their timing, and both are controlled as to time by a single lever.

Full pressure lubrication is effected by means of a triple pump; one section of the pump draws oil from the reservoir and forces it through the various leads to the bearings; the second draws oil from the forward, and the third from the rearward end of the sump, both forcing the oil through a filter of large surface area and discharging into the reservoir. The reservoir is very accessible for inspection and cleaning. The triple oil pump is located inside the lower half of the crankcase at its rear end, and can be

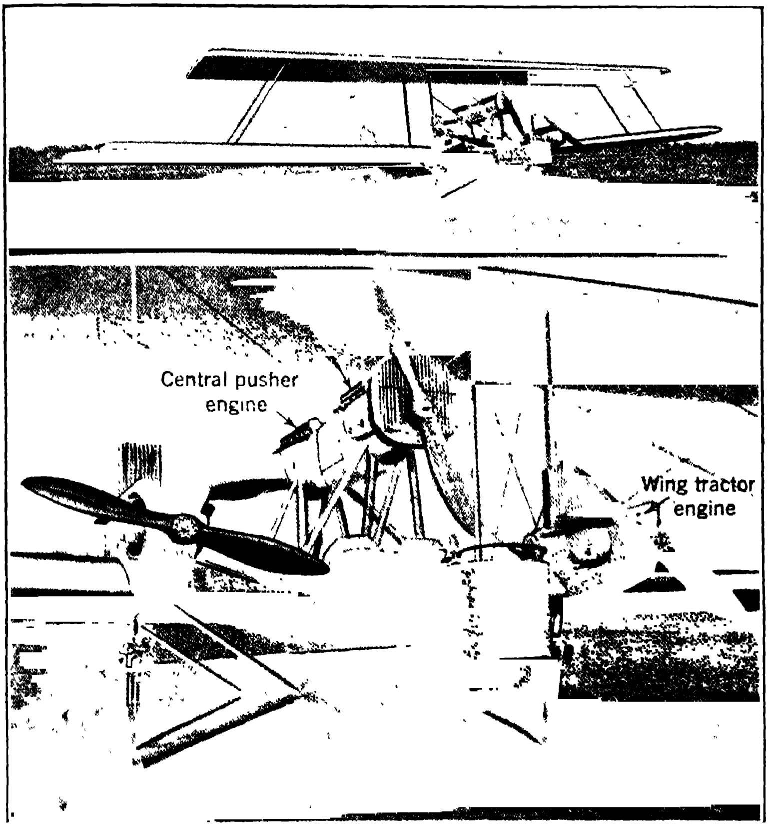


Fig. 745C.—View at A Shows the Caproni Ca 79 Biplane Which Has a Lower Wing Span of 80 Feet and a Gross Weight of Twelve Tons. It is Fitted with Four Isotta Fraschini ASSO 500 Engines Which Gives it 2000 Horsepower. B Shows the Method of Installing the Engines. The Large Size of This Airplane can be Better Understood by Comparing it with the Men Standing Under the Lower Wing in the Upper Illustration.

easily removed when required. A pressure-relief valve is combined with the pump. Cooling water is circulated by a centrifugal pump with double outlet, for connection to the two rows of cylinders. Starting is effected by means of compressed air which carries gasoline vapors in suspension. The air is distributed to the different cylinders by a rotary distributing valve which is driven through bevel gears from the vertical shaft of the timing

gear. The compressed air is either taken from a reservoir carried on board or may be supplied by a separate motor-compressor group. The weight of the engine, dry and without propeller hub, is 880 pounds, and with propeller hub, 924 pounds. This is equivalent to 1.69 pounds per horsepower at maximum and 1.78 pounds at normal output. A sectional view of the engine is given at Fig. 745, this showing the valve operating mechanism and cylinder construction very clearly.

Isotta Fraschini is among the very few companies disposing of a variety of motors large enough to fit any conceivable type of airplane. The graduation goes from 80 hp. up to 1200 hp. Both water-cooling and air-cooling are used according to the type of engine, and all the larger motors are being furnished either with or without reduction gears.

The world-wide reputation enjoyed by Isotta Fraschini has been gradually built up at the price of patient and sometimes extremely costly efforts: since the very beginning Isotta Fraschini has aimed at a maximum of power per pound of weight combined with a minimum of fuel consumption, a reduced cross section area of engine and an absolute reliability in operation. The Company feels that this goal has been reached for all of the models which are now in production. In connection with the factor "weight," it may be of interest to point out that Isotta Fraschini has been the first company in Europe to make an extensive use of electron, which is an especially light magnesium alloy whose weight ratio to that of aluminum is 1.8 to 3. The advantages of this alloy proved important enough to make it necessary for Isotta Fraschini to erect a special foundry for electron castings At present practically all the parts which were formerly in heavier aluminum alloys are electron castings or forgings.

Isotta Fraschini has developed a complete series of engines so as to meet all possible requirements both for power and service. Each single engine of the "ASSO" group has been developed for a very definite purpose and with a view to solving some specific problem connected with the development of new airplanes. However, all the engines of the "ASSO" group have certain characteristics in common, and this fundamental idea, together with that of an amazing simplicity of lines and details, is carried through so systematically that the knowledge of one of the many types implies automatically a sufficient understanding of all the points which make for a correct maintenance of any of the other engines of the "ASSO" family. The principle involved is of course of an undeniable practical value both to military and commercial aviation, inasmuch as it greatly reduces the difficulties connected with the efficiency required of the mechanics in charge of maintenance. Furthermore, it is obvious that said principle would bring enormous advantages to a military aviation which would adopt for its various types of planes (observation, fighting, day-bombing, night-bombing, etc.) the corresponding engines of the "ASSO" family. Italian aviation, which is using many thousands of these engines, has in fact already greatly benefited both in operation and maintenance by the similarity of design and construction which is peculiar to all types which form the "ASSO" group.

Some of the engines, for example:

The "ASSO" 200-hp.
" " 500-hp.
" " 500-hp. Ri (with reduction gear)

CHARACTERISTICS OF ISOTTA FRASCHINI AVIATION ENGINES TYPE "ASSO"

Type "ASSO"	Hp. Normal	R.P.M Normal	Number of Cylinders	Bore mm	Stroke mm	Cubic Displacement liters	Compression Ratio	Weight with Hub Kgs	Consumption gr per Hp hr		Reduction Rates	Cooling	*Use*
									Gasoline	Oil			
80 T	80	1400	6 in line	95	140	5.95	5.5	110	230	10	1	Air	Tourism
100	100	1400	6 in line	120	130	8 82	5 25	130	225	10	1	Water	School
200	240	1600	6 in line	140	160	14.78	5 7	280	215	10	1	Water	Observation
250 Ri	280	2000	6 in line	140	160	14 78	5 7	330	220	10	1.5 1.72	Water	Observation and Transportation
Ca	400	2200	12-V	125	140	20 61	5 5	320	225	15	1	Air	Fighting
500	518	1850	12-V	140	150	27.71	5 7	430	215	15	1	Water	Observation and Transportation
550 Ri	560	2150	12-V	140	150	27.71	5 7	495	220	15	1 5 1 72 2.17	Water	Bombing and Transportation
750	750	1600	18-W	140	170	47.10	5.7	580	215	15	1	Water	Bombing and Transportation
850 Ri	850	1950	18-W	140	170	47.10	5.7	660	220	15	1 5 1 72	Water	Bombing and Transportation
1000	1000	1600	18-W	150	180	57.25	5.5	785	215	15	1	Water	Bombing
1200 Ri	1200	1950	18-W	150	180	57.25	5 7	960	220	15	1.5 1 72	Water	Bombing and Transportation

The "ASSO" 500-hp. AQ (super-compressed for altitude work)
" " 750-hp.
" " 1000-hp.
" " 1200-hp. Ri (with reduction gear)

have many parts which are interchangeable, as, for instance, the pistons, the cylinders together with the cylinder heads, valve gears, camshafts, valves and springs, etc., as well as the oil pumps and the lower parts of the crankcase. The principal characteristics are tabulated on page 1555.

QUESTIONS FOR REVIEW

1. What is an important factor to be considered in aviation engine design?
2. What are future possible developments in aviation engine design?
3. Describe the Junker L5 aviation engine.
5. Name some distinctive features of A D C Nimbus engine
5. What distinctive feature characterizes the Beardmore six-cylinder engine?
6. Describe operation of the A.M Fuel pump
7. How does the Panhard aviation engine differ from others?
8. What is the diffe ce between the Rolls Royce type F and Condor aero engine?
9. What type of oil cleaner is used on Renault engines?
10. What is the distinctive characteristic of the Salmson water-cooled engine?

CHAPTER XL

WATER-COOLED ENGINE INSTALLATION

Designing Water-Cooled Engines Into Aircraft—Air Resistance Characteristics of Engines—Value of Inverted Engines—Conventional Engine Placing—Cantilever Motor Mounts of Tubing—Placing of Pilot Relative to Engine—Mounting Engines in Wings—Properties of Steel for Engine Mount Construction—Nature of Duralumin—Properties of Duralumin—Preventing Corrosion of Metal—Effects of Radiator Position on Airplane—Flight Control of Cooling Capacity—Altitude Effects on Performance—Cooling Systems, Specifications for Installation—U. S. Air Service Engine Installation Specifications—Engine Mounting—Engine Controls—Lubricating System—Cowling—Ignition—Fuel System—Leakproof Tanks—Crashproof Tanks—Exhaust System—Plumbing Troubles—Causes of Airplane Accidents—Fuel Tanks and Supply Systems—Fuel Pumps—A.C. Fuel Pump—Pressure System has Fire Hazards—Oil and Fuel Tank Location—Duralumin Fuel Tanks—Unpacking Curtiss D12 Engine—Installation of Curtiss D12 Engine—Wiring and Controls—Cooling System—Water and Denatured Alcohol Anti-freezing Mixture—Glycerine and Water Anti-freezing Mixture—Mounting Propeller on Curtiss D12 Engine—Lubricating System, Curtiss D12—Operation of D12 Engine—Starting Procedure—Observations at Start—Oil Pressure Regulation—Carburetor Settings—Care of D12 Engine in Storage—Details of Engine Control.

Designing Water-Cooled Engines Into Aircraft.—Most of the single engine airplanes of late design using water-cooled engines have powerplants ranging from 400 to 600 horsepower, especially those intended for air mail or express or passenger carrying, and also the types for military service. Now that there are various types and makes of engines to select from, the engine is designed into the airplane instead of the structure being designed around the engine as was formerly done when only a few types of engines were available. The twelve-cylinder Vee type engine is by far the most popular and it can be had in direct drive and geared down types, as well as in designs that can be installed with the cylinders inverted. An important consideration is propulsive efficiency and the streamlining of the fuselage front end is important so that a minimum amount of the propeller disc area will be masked by the cowling around the engine.

There is also another influence and that is the vision obtained by the pilot directly ahead and also directly down to insure good landings. Effective streamlining of the Curtiss engine in the Hawk seaplane reduces the loss of propulsive pull of the aerial screw by having a minimum masked area. The various airplanes shown at Fig. 746 show how the various types of engines may be installed to secure good streamlining, vision and reasonable aerodynamical efficiency. The conventional direct drive motor is installed in the structure shown at A. It will be seen that in order to obtain good vision that the engine crankshaft, which is also the center line of propulsive, or rather tractive effort comes well below the center of the biplane cellule, where one may assume the center of gravity of the entire structure to be located.

When a geared form of engine is installed, it will be apparent that with the same engine location as at A, Fig. 746, the center line of tractive effort

is raised in B by raising the propeller driveshaft center line so it more nearly coincides with the assumed center of gravity. Besides the advantage of bringing the line of thrust higher, the type of engine shown in B permits of higher horsepower output for the same weight because the engine can be run faster and also makes for higher propeller efficiency because

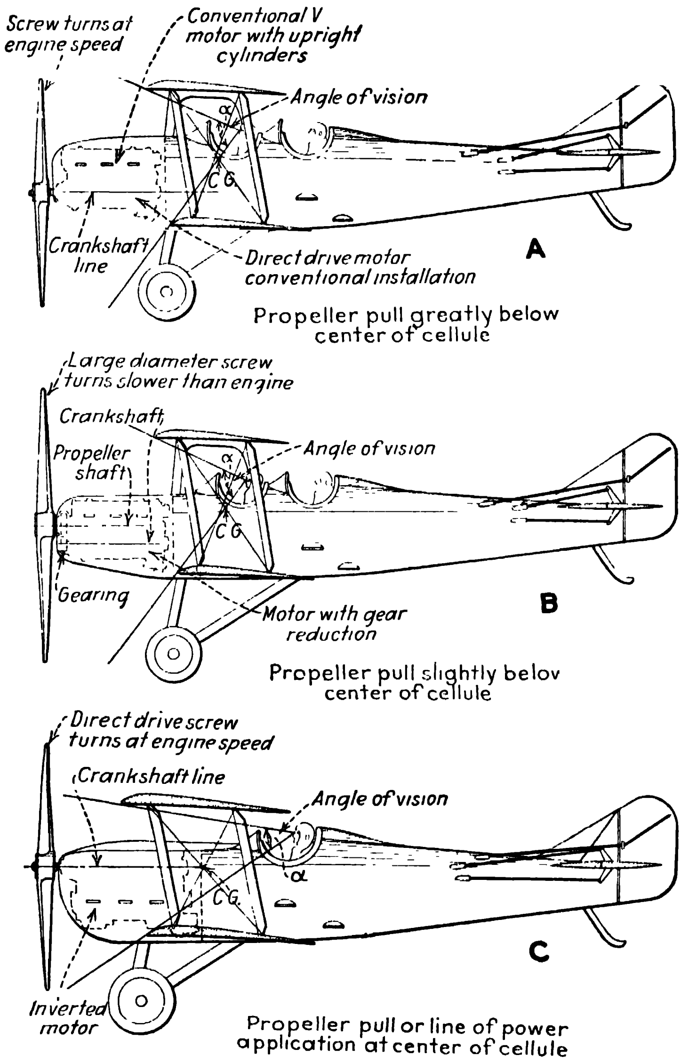


Fig. 746.—Diagrams Showing Installation of Various Types of Water-Cooled Engines in Fuselage to Secure Good Vision and Proper Aerodynamical Advantages. A—Direct Drive Propeller. B—Gear Drive Propeller. C—Inverted Crankshaft, Direct Drive Type.

a larger diameter and slower screw can be used with a geared engine than with a direct drive form.

In a fast plane where maximum maneuverability is sought, as in the single seater shown at Fig. 746 C, a coincidence of the tractive effort line and the center of gravity is possible by using an inverted engine and aerodynamical efficiency is obtained without greatly sacrificing the factor of vision by carefully streamlining the front of the fuselage.

Air Resistance Characteristics of Engines.—Some interesting figures were given by Grover C. Loening, pioneer aeronautical engineer and inventor of the amphibian land and seaplane in a paper read before the S. A. E. in which some interesting conclusions were reached and results tabulated.

One might condense the general sentiment of the aviation world with regard to fast machines by pointing out that the light-weight high-powered radial air-cooled engines are generally considered the coming type for small fast commercial aircraft; while the large, heavy high-powered water-cooled engines are generally placed in large, slow, load-carrying airplanes. Further than this, there is a distinct tendency on the part of engine builders to sacrifice some details for the purpose of lightening the weight of the engine, "dry," in pounds per horsepower. The engine builder is only too likely to think that he has reached the goal required by the aircraft builder if he can make this figure low enough. Mr. Loening proposed to demonstrate that this attitude is not only erroneous, but actually tends to the development for aircraft of engines that are very undesirable for several important reasons.

It will be found on proper consideration that we do not penalize engines by placing them in different types of aircraft, and are thus justified in considering figures on a unit horsepower basis.

It has been found quite conclusively on many types of aircraft using water-cooled engines that, no matter where the radiator is placed, a certain amount of head resistance must be expended to get cooling, since the air must pass through the radiator. Placing the radiator in front of an engine, in an effort to combine the resistance of the two, merely makes it necessary to add to the size of the radiator by exactly the amount that the presence of the engine behind it blocks circulation. This is particularly true of the Liberty engine when mounted on the De Haviland-Four. A review of the sizes of various well-placed radiators gives the values for frontal areas presented below.

This reduction in size of radiator, of course, involves the consideration that on a high-speed machine the radiator be retractable.

Speed, m.hp.	Frontal Area of Radiator, per Horsepower sq. in.	Lift/Drift Ratio
50	2.5	1 to 8
100	2.0	1 to 11
150	1.5	1 to 11
200	1.0	1 to 10

Mr. Loening made some computations and presented a chart in developing his discussion that permitted an interesting demonstration when the figures for the Curtiss C12 were used for an example and assumed first that by laborious work the weight of the engine was reduced to one-half its amount, which it is very doubtful could ever even be approached in this type of engine. Assuming such an extreme, however, we find the resistance per horsepower, when reduced as shown, permits an increase in speed from 232 to 241 miles per hour or only nine miles per hour. On the other hand, we can take this same engine and assume that, keeping its weight the same, we modify its structure so as to halve the head resistance of the engine itself, due to its shape. This change, which is entirely within the realm of possibility, would increase the speed to 290 miles per hour, and would show that if we could get a 420-horsepower engine with a cross-sectional area permitting a good shape that would not be much over two feet high and nine inches wide, we could approach a speed of 300 miles per hour. Even admitting that some of the assumptions made necessary to derive this line of reasoning are apt to vary, we nevertheless find a lesson of the greatest importance which promises much in the future of aviation. This shows how much more important the head resistance of an engine is than its weight. Mr. Loening urged the builders, therefore, to abandon their unwarranted race for lighter weight per horsepower, bringing with it tremendous expense in construction, a lack of reliability and innumerable difficulties in service, and suggested that they begin on a new line offering far greater possibilities by making the shape and disposition of their engines more suitable to airplanes, with low head resistance considered as a fundamental. An engine of sufficiently well-studied shape will permit greater weight, more reliability, and less construction expense without a sacrifice of aerodynamical efficiency. Mr. Loening has been an advocate of inverted cylinder Vee engines for some time past and some models of the Amphibian, which is the product of his genius, use an engine with the crankshaft placed above the cylinders. This type permits the use of a larger diameter tractor screw and also materially lowers the center of gravity of the powerplant. Other models are equipped with radial cylinder air-cooled engines.

Value of Inverted Engines.—An inverted engine when used in airplanes, possesses four major advantages. First, in the usual type of single-engine tractor airplane, the pilot's vision straight ahead is seriously obscured by the cylinders and cowling of either a Vee-type or a large radial-type engine. He is practically compelled to swing the airplane from its true course to obtain a view along the normal line of flight. It is unthinkable that poor vision dead-ahead, such as this, will be tolerated when the air is as full of airplanes as we expect it to be in the future. Collisions in the air, even today, are far more numerous than would be the case if poor visibility conditions did not exist. With an inverted engine, as shown in Fig. 746 C, the cowling in front of the pilot can be made in slope to meet the line of the propeller-hub, in this way, favorable vision can be secured. The second major advantage of the inverted engine lies in the high center of thrust that ensures better flying qualities, in that it offsets the tendency of the airplane to climb when full power is on. This is also shown in illustration.

The additional propeller-tip clearance is also desirable from a consideration of taxiing over rough ground and, in some cases, removes the limitation on the diameter of the propeller that would otherwise exist with a direct drive, conventional installation as shown at Fig. 746 C and to a lesser degree with a geared drive screw installed in an engine with upright cylinders.

A third point in favor of the inverted engine is its accessibility to a mechanic working on the ground. If the engine mounting is properly designed and the cowling suitably arranged, the engine can be readily worked on from the ground without the necessity for stepladders and other equipment. Furthermore, the crankcase covers can be removed and the bearings examined, should this be desirable.

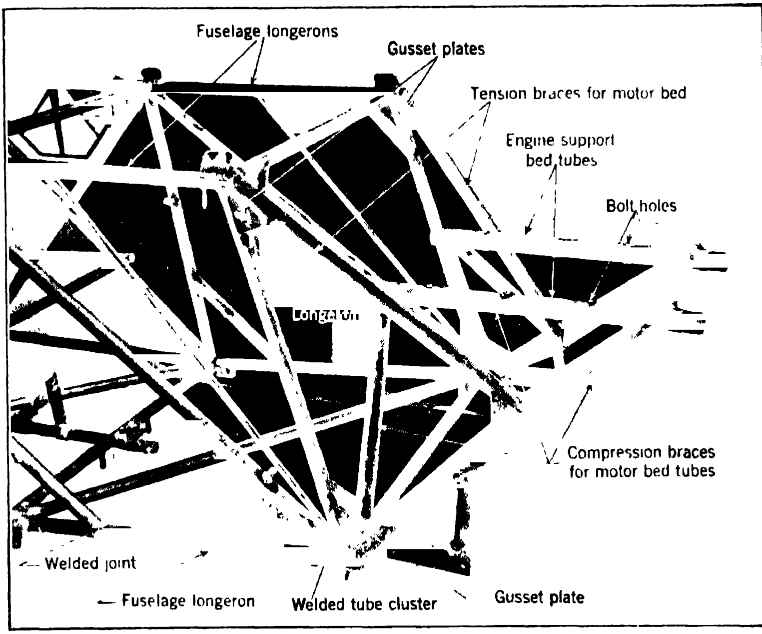


Fig. 747.—Typical Motor Mount for Curtiss OX5 Motor Made of Braced and Welded Alloy Steel Tubing.

The fourth point in favor of the inverted engine has regard to the location of the carburetors that, in many installations, will allow gravity fuel-feed and will avoid the use of complicated piping and pumping arrangements. The fire risk is also diminished to a certain extent with this arrangement, for gasoline leaks are confined to the extreme bottom of the installation, and covering the whole exterior of the engine with gasoline, as is normally the case, is not possible, as any leakage of fuel will drip off to the ground or into suitable catch basins or tanks intended to receive it.

Conventional Engine Placing.—In installing the conventional type of aviation engine of the twelve-cylinder Vee water-cooled form, modern practice is to use a simple frame made up of alloy steel tubing welded to fittings to form suitable joints as shown at Fig. 747 which shows a typical

mounting for an OX5 motor. The engine bed tubes are supported by double braces in the form of triangular assemblies these in turn being braced to the front end of the fuselage frame by substantial diagonals extending from the top fuselage longeron tubes to triangular bracing members under the engine support tubes. These latter are horizontally placed and are pierced with holes to receive the engine bed bolts. It will be noted that the tube is not weakened appreciably because steel tube ferrules are driven into the bolt holes and are welded to the top and bottom walls of the engine bed supports. The attention of the reader is directed to the gusset plates at the corners where the engine supporting frame joins the fuselage tubes, also at the points of juncture of the diagonal tubes and bed support braces. The gusset plates are welded in place and greatly increase the strength of the joints.

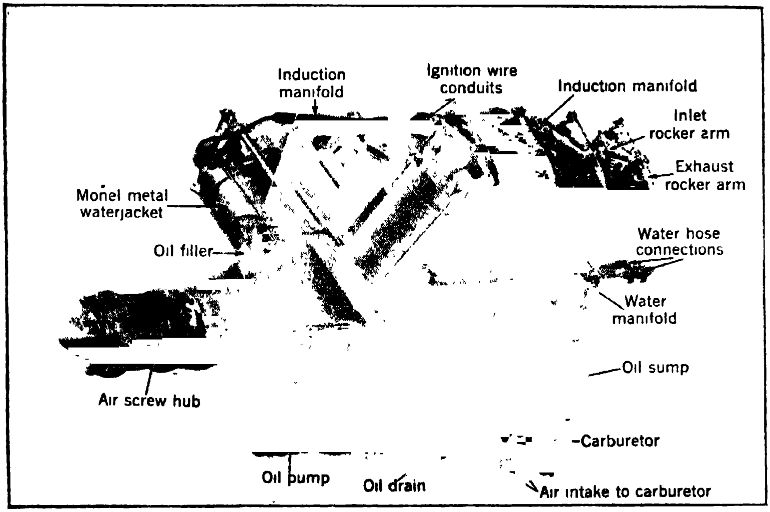


Fig. 747A.—Type of Motor, Curtiss OX Series Mounted on Engine Support Shown at Fig. 747.

Cantilever Motor Mounts of Tubing.—Another installation of merit is shown at Fig. 748. This also is composed of alloy steel tubes welded into a substantially braced assembly. This differs from that design shown at Fig. 747 however, in that the entire engine supporting frame may be removed from the fuselage front end by removing four bolts, one at each corner of the fuselage, clearly indicated in the illustration. Substantial fittings having projecting ears form the corners of the fuselage and the yoked ends of the engine support frame tubes fit these ears. The frame illustrated is used on the Gates-Day New Standard biplane. The engine is an eight-cylinder Hispano-Suiza. It will be observed that wood filler pieces are placed between the engine supporting arms and the steel tubes forming the engine bed to absorb engine vibration. This illustration is also of value

because it shows the radiator and oil tank installation, also the simple oil and water piping made possible by the placing of the water pump relative to the radiator and the engine oil pump relative to the oil tank. The method of hanging the radiator by lugs at the top and a strap at the bottom is also depicted.

The six-cylinder-in-line engine is a form that lends itself readily to installation in the airplane fuselage. A typical foreign application,—that of the Albatross L75 is shown at Fig. 749. As will be seen from the illustra-

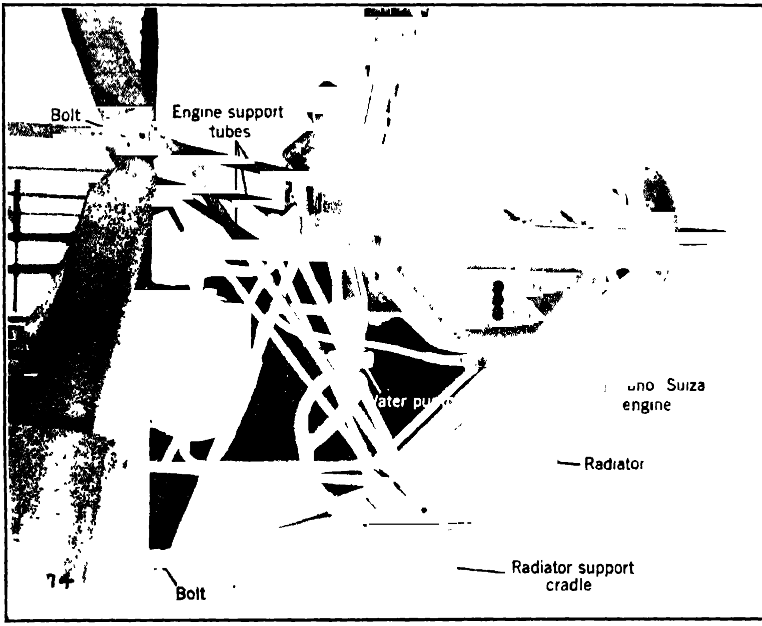


Fig. 748.—Motor and Radiator Mount of Gates-Day New Standard Biplane is of the Cantilever Type, Built of Alloy Steel Tubing Welded and Braced at Joints and Attached to Fittings at Front Fuselage Bulkhead by Bolts. Note Method of Bracing by Diagonal Tubes and Welded Gusset Plates.

tion the usual braced cantilever beam type of engine supporting frame made of steel tubing is attached to the front end of the fuselage longerons. The engine supporting frame is detachable. A supplementary tubular section frame carrying the aluminum nose piece and a ring encircling the propeller shaft shown facilitates attaching the hood cowling which is removable to give ready access to all parts of the engine, which is exposed as shown in the illustration when the cowling is removed. The location of the radiator, fuel and oil tanks and various auxiliary elements are clearly shown in this view. The six-cylinder engine is a popular type in Germany and many airplanes use such engines for power.

Another interesting foreign installation is shown at Fig. 750. This is the front end of a Dornier-Merkur, powered with a twelve-cylinder Vee BMW motor of the water-cooled type. In this case the cowling is so arranged that the top cover, which is held by hinges at the rear may be

tilted up and back as shown and the side cowls folded back to permit a workman standing inside the engine compartment if work on the top of the engine is necessary. The location of the shuttered radiator below the nose of the fuselage where it is exposed to the airstream is also shown in this view.

Placing of Pilot Relative to Engine.—In practically all European transport-airplanes the pilot sits directly behind the engine. While this position affords him better visibility and simplifies the controls leading to the engine section, it has the two disadvantages that (a) the problem of proper balance for both the full-load and empty conditions is troublesome, and (b) the danger to the pilot in the event of a crash is acute. For night flying and

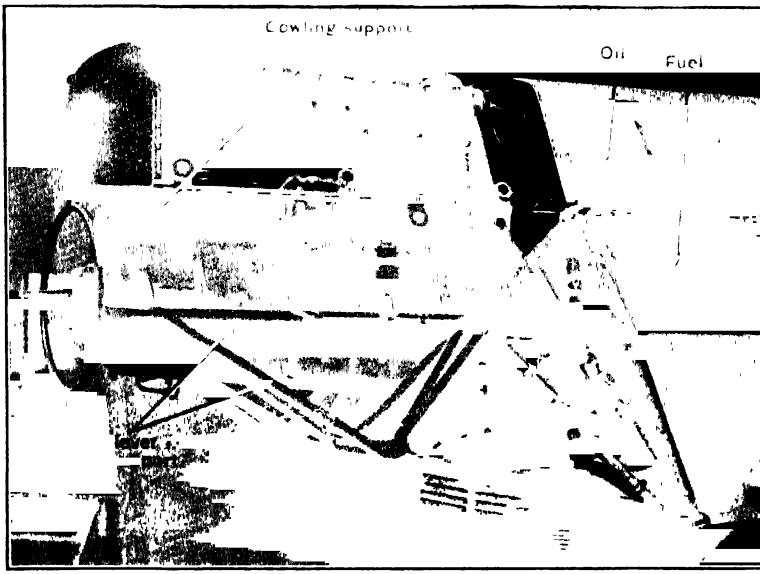


Fig. 749.—Cantilever Engine Mount of Steel Tubing Used on Albatross 75 Airplane. Note Auxiliary Frame of Light Steel Tubing to Which Cowl is Attached.

for flying with bad weather conditions in mountainous country, most of the Air Mail pilots prefer to sit far aft. The disadvantages of the position aft are that (a) all controls to the engine section must be carried forward under the floor; (b) visibility is not so good as it should be, although in this case it works out fairly well, particularly as an adjustable seat is provided; and (c) it is difficult to heat the cockpit properly. In an airplane with as many controls as are necessary on the mail plane, the location of the engine-section controls under the floor creates a very troublesome condition, although the use of Ahrens control-units eliminated much of the work and maintenance trouble incidental to the use of bellcranks.

In this country, the pilot of large transport planes is usually placed forward of the passenger cabin and back of the nose motor in order to give him the proper vision. In small commercial airplanes of the open cockpit type, the pilot sits in the rear cockpit and the passengers, who are located

on the approximate center of pressure, sit in the front cockpit and back of the engine. In small cabin planes, the pilot is usually forward of the passengers and back of the engine.

Mounting Engines in Wings.—Recently, three separate projects considering the use of no less than 10,000 horsepower in a single plane were

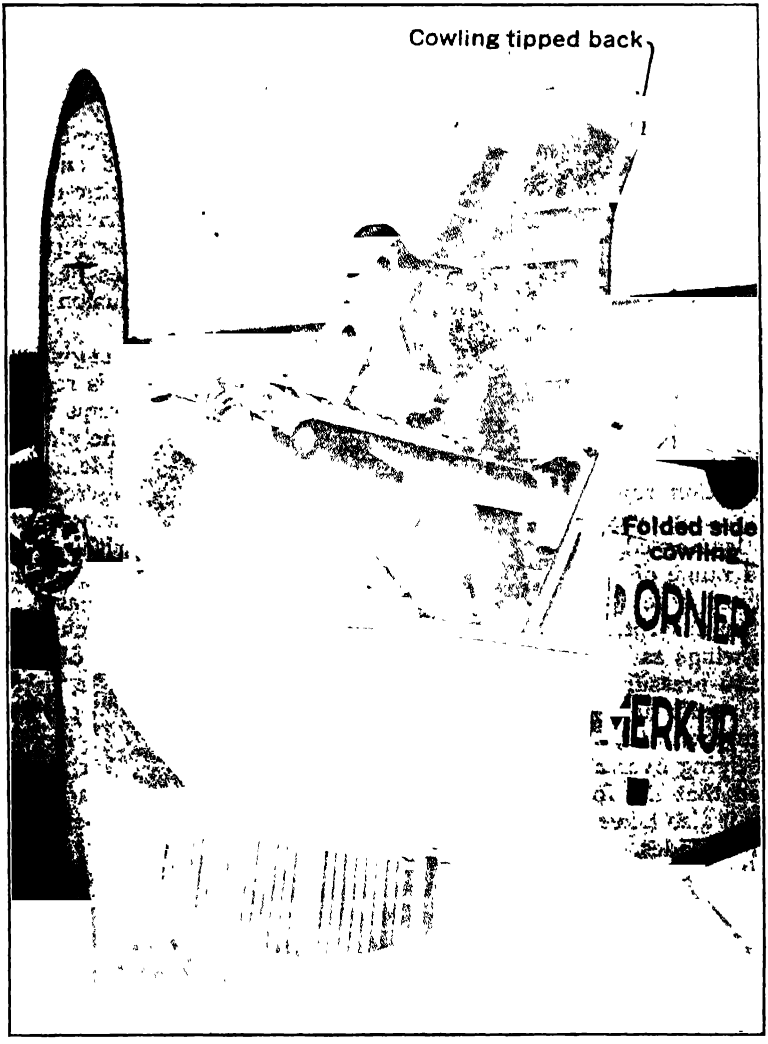


Fig. 750.—Engine Installation in Dornier "Merkur" Monoplane Has Hinged Cowl to Cover Motor and Folding Side Panels that Give Ready Access for Top Overhaul, as Shown in Illustration.

announced and we must consider such designs as indicative of what we may expect in the future. The designs of these tremendously large planes are all of the thick-wing cantilever monoplane type, with cabins and engine

rooms enclosed in the wings. The designs include multiple powerplants, in some cases with tractor propellers mounted in front of the leading edge and in other cases with pusher propellers aft of the trailing edge. Although such designs seem fantastic to us at the present writing we must realize that the general traveling public will not be able to take advantage of aerial transportation on a large scale until such planes actually are built and are operating safely. One man with superb courage proved that he could cross the Atlantic alone in a flight from New York to Paris. That was a very thrilling episode but, so far as public utilization of air travel is concerned, in the opinions of leading aeronautical engineers, as reflected by discussions printed in the *S. A. E. Journal,* we need planes capable of crossing the Atlantic with at least 100 passengers. Such planes will demand enormously powerful engines, and it is inconceivable that the great parasitic-resistance of many externally mounted air-cooled powerplants can be permitted. Further, the need for convenient access to the engine for minor repairs and adjustments during flight will also require that the engines be suitably housed within the wing, which leads naturally to the conclusion that the engines should be water cooled.

An additional good reason for the use of the water-cooled engine relates to ice formation on the wings and fuselages of planes, which is recognized as a serious handicap in transatlantic flights. While it is perhaps too early to make a positive assertion of this nature, it seems that if the plane were equipped with the wing-skin type of radiator it would be feasible to prevent ice formation, especially since it has been shown that the dangerous effects of this phenomenon are confined to restricted portions of the wings, notably at the leading edge. The danger is believed to exist only within a rather limited range of temperature and an equally limited zone of saturation of the atmosphere with water vapor. Presumably, ice is formed as a result of either absorption of latent heat through evaporation on such surfaces of the wings as are subjected to sub-atmospheric pressures or of local increase in pressures which, occurring in a saturated atmosphere, naturally would result in condensation. Regardless of the cause, the problem is definitely with us, and its solution cannot be shirked if we are to have year-round flying over all conceivable routes. In this connection it should be realized that the formation of ice is not confined to the surfaces of the wings; it also takes place on all exposed parts of the airplane, including the propeller blades.

Although many aeronautic authorities are agreed on the feasibility of the giant thick-wing monoplane, progress in this direction naturally is hampered by the enormous amount of money required for such an undertaking. In this respect the situation is very similar to that of large dirigible development, which is being greatly retarded by difficulty in interesting capital in such ventures. One of the chief reasons for the rapidity in growth of commercial aviation along present lines is that such planes as are now being used can be built for a very modest expenditure, such as $15,000 or $20,000, and it would require 200 or 300 times as much money to construct a large dirigible or an airplane of the vast size contemplated. Powerplants inside the wings are being considered by Junkers, Rohrbach and other European designers.

Properties of Steel for Engine Mount Construction.—Steel is used in many parts of the airplane fuselage and especially for engine mountings as illustrated in Figs. 747 to 750 inclusive and while there has been a wide range of ferrous alloys to choose from, engineers have felt that most useful purposes would be served by concentrating on the use of a relatively small number of alloys. The properties of steel tubing, compared to those of duralumin, as recommended by the S. A. E. are such that practically all needs may be met without radical departure from the strength values given.

The adoption of specific strength values for structural materials filled a long-felt want of the designer and eliminated many points of controversy that have always existed between different schools of metallurgists and designers. These values are summarized below, all values being in pounds per square inch of sectional area.

COLD ROLLED MEDIUM CARBON STEEL (SAE 1025)

55,000	Tensile strength
35,000	Yield point
90,000	Bearing strength (except hinges)
60,000	Bearing strength for hinges and where subjected to stress reversals
55,000	Compression strength
35,000	Shearing strength

HEAT TREATED DURALUMIN (17ST)

Sheet	*Bar*	*Tubing*
55,000	55,000 (¾" diam. and below) 50,000 (above ¾" diam.)	55,000 tensile str.
30,000	30,000 (¾" diam. and below) 25,000 (above ¾" diam.)	30,000 yield point
75,000	75,000	75,000 bearing str.
27,000 (abv. $\frac{1}{16}$" thick) 20,000 (bel. $\frac{1}{16}$" thick)	30,000	27,000 shearing str.

CHROME MOLYBDENUM STEEL TUBING (AS RECEIVED)

95,000	Tensile strength
60,000	Yield point
80,000	Tension near welds
50,000	Shear near welds
60,000	Shear unwelded
125,000	Bearing, near welds
140,000	Bearing, unwelded

HEAT TREATED ALLOY STEELS

(Chrome Molybdenum, chrome vanadium, 3% Nickel S.A.E. 2330)

Ultimate Tension	*Yield Point*	*Bearing Strength*	*Shearing Strength*
100,000	80,000	140,000	65,000
125,000	105,000	175,000	80,000
150,000	125,000	190,000	100,000
180,000	140,000	200,000	115,000

The bearing strength to be reduced to 125,000 near welds.

The steel work of a fuselage, especially fittings, being highly stressed, it is especially necessary to protect it against salt water corrosion when used in seaplanes. This may be done by a variety of processes, some depending on electrical deposition of noncorrosive metals or by painting the tubes and fittings with enamels or rust resisting compounds.

Nature of Duralumin.—Duralumin is an aluminum alloy containing copper, manganese and magnesium. Its strength and toughness are comparable with those of mild steel, and are obtained with a specific gravity of 2.81 as against 7.80 for steel. The melting-point is approximately 655 degrees Centigrade (1,211 degrees Fahrenheit), the recalescence-point is 520 degrees Centigrade (968 degrees Fahrenheit), the annealing temperature is approximately 360 degrees Centigrade (680 degrees Fahrenheit) and the coefficient of expansion is 0.0000225 per degree of temperature Centigrade (1.8 degrees Fahrenheit). The chemical composition of the alloy varies within the following limits: copper, three to five per cent; magnesium, 0.3 to 0.6 per cent; manganese, 0.4 to 1.0 per cent; and the remainder is aluminum plus impurities. Small quantities of other metals are added sometimes for certain specific reasons. For instance, chromium can be added to increase the burnishing qualities of the metal.

The relative modulus of elasticity of duralumin is about one-third that of steel. The Bureau of Standards gives its value as being between 10,000,000 and 11,000,000 pounds per square inch. Steel is quoted generally as having a modulus of elasticity of 29,000,000 pounds per square inch.

In duralumin forgings where the sections are heavy, it is advisable to lower the minimum tensile-strength requirements to 50,000 pounds per square inch; a proportional increase in elongation will be found. Duralumin is unaffected by mercury, is nonmagnetic, withstands atmospheric influences and offers a remarkable resistance to sea and fresh water if properly protected. It does not tarnish in the presence of sulphureted hydrogen; and it takes a polish equal to nickel-plating and remains bright without cleaning longer than any plated or silvered article. It is the ideal substitute for aluminum, German silver, brass, copper, nickel-plated and silvered articles, and is the only substitute for steel where lightness combined with the strength of that metal is required. It is the only light metal that can replace steel in forgings, with a two-thirds saving in weight. Heat-treated duralumin forgings approximate mild-steel forgings in strength. Wherever weight is a deciding factor, duralumin is the most satisfactory metal for most shapes made by hot-working or forging. Naturally, duralumin forgings are especially desirable for reciprocating or moving parts where inertia, due to their own weight, forms a large part of the total stress. Duralumin machines and polishes very easily and, as it does not rust or corrode, it can be used in many places where weight is not the prime essential.

Properties of Duralumin.—Annealed duralumin can be heat-treated and the maximum physical properties obtained, no matter what the shape or form to which the metal may be reduced. Conversely, heat-treated duralumin can be annealed.

Duralumin can be cold-worked after heat-treatment and aging. This operation produces a hard, smooth finish and materially increases the ten-

sile-strength which will increase from 6,000 to 10,000 pounds per square inch over that of the heat-treated metal, but the elongation may drop as low as three or four per cent.

In the annealed form it can be drawn, spun, stamped or formed into a great variety of shapes, as is the case of brass and mild steel. The physical properties in this state average as follows:

Ultimate Tensile-Strength, lb per sq in.,	25,000 to 35,000
Elongation in 2 In., per cent,	10 to 14
Brinell Hardness	54 to 60
Scleroscope Hardness	9 to 12

Duralumin in its heat-treated form can be slightly shaped or formed and can be bent cold to 180 degrees over a mandrel four times the thickness of the sheet. Its remarkable tensile-strength is here combined with its maximum elongation as follows:

Ultimate Tensile Strength, lb. per sq. in.,	55,000 to 62,000
Yield-Point, lb per sq in.,	30,000 to 36,000
Elongation in 2 In, per cent,	18 to 25
Brinell Hardness,	93 to 100
Scleroscope Hardness,	23 to 27

Heat-treated duralumin forgings have similar physical properties. Heat-treated and hard-rolled duralumin is used where no bending or forming is required It is a very hard, strong, springy metal in this state and machines or polishes beautifully. Its physical properties in this form average as follows:

Ultimate Tensile-Strength, lb. per sq. in.,	67,000 to 72,000
Yield-Point, lb per sq. in,	55,000 to 65,000
Elongation in 2 In, per cent,	3 to 8
Brinell Hardness,	130 to 140
Scleroscope Hardness,	37 to 42

Preventing Corrosion of Metal.—Corrosion of duralumin has been compared with rusting in steel and must be taken care of by protective coatings. These may be applied by painting or electrolytic treatments. Some insulating material must be interposed between the duralumin surface and the corroding elements. Linoil, manufactured by Berry Brothers of Detroit, is an antirust material produced through treatment at high temperature of a combination of several oils. Its preserving action for all metals is such that a polished iron-plate covered in part with Linoil and exposed to dampness does not show any alteration in the protected part after being in contact with damp ground or damp air for a long time, whereas, the part not covered with Linoil becomes entirely rusty. Repeated tests under all forms have given the best results even subject to the action of acids and to that of certain alkaloids.

It is especially in aviation that Linoil has played an extremely important part. Duralumin may, at the present time, be efficiently protected against the harmful influences of dampness, of sea water, and even of acids.

The first tests carried out at the Naval Establishment of Saint-Raphael, in France have enabled one to appreciate that the nonprotected samples of duralumin quickly deteriorated, whereas those protected by the ordinary

methods resisted longer, and that those treated with Linoil were absolutely intact. Linoil is applied with great facility, either with a brush or by means of dipping or spraying processes or any other method according to the importance and possibilities of upkeep of the part to be protected. It flows very easily and covers about 600 square feet of smooth and dry surface per gallon. Once applied, it is transparent, extremely durable and gradually becomes harder and harder, and after drying it may receive any paint whatsoever, to which it imparts great durability. "Linoil Clear" is said to be used by many of the leading constructors, both for land and sea machines, as the only dope which absolutely protects duralumin and renders both wood and fabric waterproof with a thickness of $\frac{1}{100}$ of a millimeter per coat.

Effects of Radiator Position on the Airplane.—The important effects of the location of the radiator on the airplane have already been stated. Such quantitative results as have been obtained to date are given there. Attention is called to the three classes of positions already defined. The unobstructed positions have the following advantages:

(1) Except for the effects of the slipstream, the air flow through the core, and consequently the heat transfer, are greater for unobstructed than for obstructed positions.

(2) The head resistance chargeable to the radiator is considerably less for unobstructed positions than positions in the nose of the fuselage, in the wing or inside of the fuselage. The effect of the slipstream is to increase the head resistance of a radiator that would otherwise be unobstructed.

(3) Since air flow is greater in unobstructed than in obstructed positions and, therefore, heat transfer per unit frontal area is greater, it follows that the weight of a radiator may be less for a given cooling capacity when in an unobstructed position than when in an obstructed position.

(4) With reduction both in weight and in head resistance chargeable to the radiator, the power absorbed chargeable to the radiator is reduced by placing the radiator in an unobstructed position, rather than in an obstructed position.

(5) With both increase in heat transfer and decrease in power absorbed, the figure of merit of an unobstructed radiator is considerably greater than that of the same type of radiator in an obstructed position.

The location of the radiator in the nose of the fuselage is objectionable because of very large absorption of power for a given cooling capacity. Not only is the resistance of the airplane much greater with a nose radiator than with the nose properly streamlined and an unobstructed radiator of equivalent cooling capacity added, but the air flow through the core is so low that with engines of the higher powers it becomes necessary to enlarge the fuselage to accommodate a nose radiator of sufficient size to cool the engine.

The performance of a radiator in the wing has not been thoroughly investigated because of experimental difficulties, but enough data are available to show that the air flow, and consequently the heat transfer, are very

low for a given flying speed, while the effect on the wing as such can only be detrimental.

The effect of the propeller slipstream is to increase to some extent the air flow and heat transfer of the radiator. No specific statement can yet be made in regard to its effect on the head resistance of radiators in obstructed positions.

The special types of core include radiators made of water tubes in the form of flat, hollow plates placed edgewise to the air stream and with no indirect cooling surface. This type has been shown to be markedly superior in respect to heat dissipation per horsepower absorbed, over the ordinary types of cellular radiator for use in unobstructed positions on planes flying at higher speeds. The mechanical weakness of the flat-plate type is an inherent disadvantage, but one that can doubtless be overcome. Radiators of the fin-and-tube type show very high head resistance and low air flow; for this reason they are unsuited for general aeronautic use.

Tests have been made on certain special types of core, made with water tubes deep in the direction of air flow, and narrow, placed side by side one behind another, with spaces between consecutive rows in each direction. These types produce a shrill whistling sound when in an air stream of more than about 30 miles per hour or fifteen meters per second, and show irregular properties. That is, the air flow through the core is not proportional to the flying speed and the head resistance is not proportional to the square of the speed. These types show very high heat transfer for a given air flow, but very low air flow for a given flying speed. They show also a very high head resistance, with the result that the heat transfer for a given flying speed is in general not high and the figure of merit is very low. The whistling types are not suitable for aeronautic use.

The information at present available on the effects of different positions on the airplane, points to the following statements regarding the types of core suitable for different positions:

(1) For unobstructed positions, the radiator should be characterized by straight smooth air passages and low head resistance.

(2) For positions in the nose of the fuselage, the head resistance chargeable to the radiator increases, for a given frontal area, with increase in air flow. The most suitable type of radiator will be one that gives a high rate of heat transfer with a low air flow. This consideration leads to the use of a compact type with a large amount of cooling surface per unit frontal area and, since the head resistance chargeable to the radiator does not increase with the head resistance of the core, cooling surface can be added, even in the form of spiral vanes or other turbulence devices, without serious detriment. Whether the turbulence devices really increase turbulence and thereby increase the heat transfer more than would be done by an equal amount of straight and smooth surface, is a question that needs further study.

(3) For positions in the wing, the requirements are probably similar to those for positions in the nose of the fuselage.

Flight Control of Cooling Capacity.—Among the more important methods proposed for the control of the cooling capacity of the radiator in flight are the following:

(1) The use of detachable sections is good for seasonal corrections such as summer and winter conditions, and for change from one latitude to another.

(2) The construction of retractable types that allow withdrawing the radiator or a portion of it into the fuselage when its full cooling capacity is not needed, is one of the best methods of control from the standpoint of heat transfer and head resistance. Only the portion of the radiator really required for use need be outside of the fuselage where it will affect the resistance of the plane. Difficulties may be encountered, however, in the design of the fuselage for such an installation of the radiator.

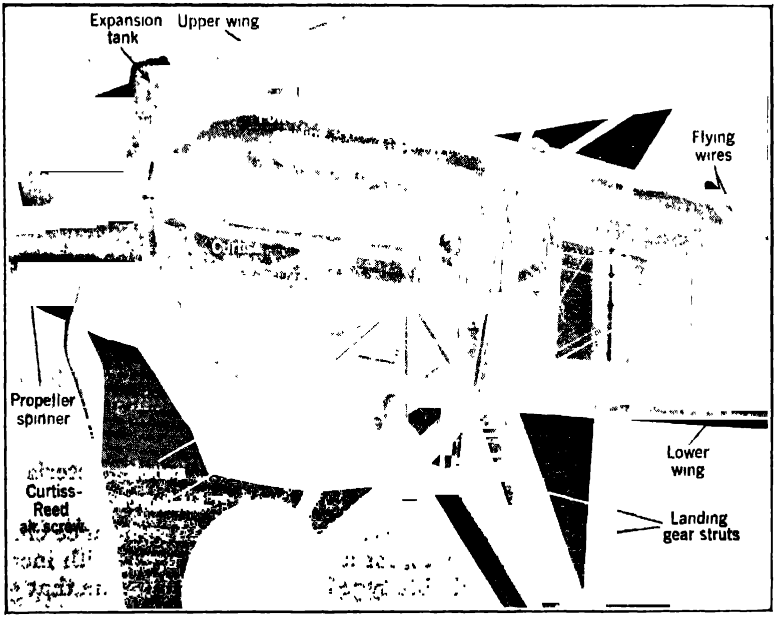


Fig. 750A.—Official Photo, US Army Air Corps Showing Use of Shutters to Control Radiator Temperature.

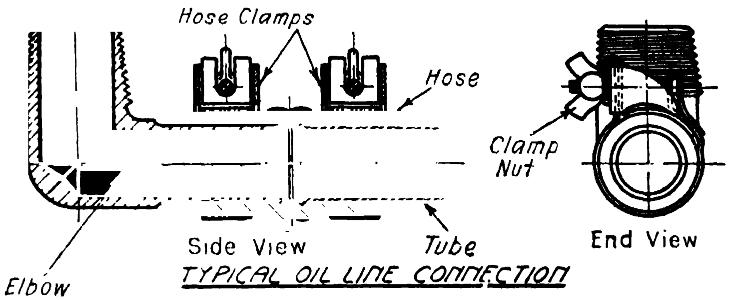
(3) Some attempts have been made to use a radiator pivoted about a vertical axis, so that it can be swung into or out from the air stream. This method is unsatisfactory because when the radiator is turned about, or yawed, on a vertical axis, the heat transfer is increased for certain angles while the head resistance is also greatly increased. This method not only fails to give satisfactory control of cooling capacity, but adds greatly to the absorption of power.

(4) If the fuselage cannot be designed to accommodate a retractable radiator, the radiator can be divided into two parts and the two

halves placed on opposite sides of the fuselage. This gives the advantage of an unobstructed position and allows control by shutters that may be two plates for each radiator, hinged at the side of the fuselage. These plates swing out and mask both the front and rear faces to any desired extent.

(5) Shutters of the window-blind type are objectionable because they add greatly to the resistance of the radiator when closed, and their effect in increasing head resistance and decreasing air flow is by no means negligible when open.

(6) Control by regulation of the water flow has been suggested, but no satisfactory method has been proposed. If the water is cut off from a part of the radiator, that part is likely to freeze at great altitudes or in cold weather; while a change in rate of flow is not practicable because, with rates commonly used in practice, the heat transfer is practically independent of the rate of flow.



Air Service Approved Typical Oil Connection.

Fig. 751.—U. S. Air Service Approved Typical Oil Connection.

Altitude Effects on Performance.—As an airplane rises to great altitudes, the decrease in density and temperature of the air have important effects upon the performance of the radiator. The reduction in temperature tends to increase the heat transfer in proportion to the increase in mean-temperature difference between the water in the radiator and the air through which it passes. The decrease in air density reduces the mass of air passing through the radiator for a given flying speed and thus tends to decrease the heat transfer by an amount corresponding, but not proportional, to the decrease in density.

Since the head resistance is practically proportional to the density of the air, the effect of the decrease in density is to reduce the head resistance for a given flying speed by an amount proportional to the decrease in density. The combined effect of density and temperature changes due to changes in altitude is to decrease the heat transfer for a given flying speed, but the head resistance is also decreased and for the higher speeds the figure of merit is in general somewhat increased. Estimates of probable densities and temperatures at altitude can be made from meteorological data, and the per-

formance of a given radiator at altitude can be estimated from its performance at ground level by the use of the equations now available for air flow, heat transfer, head resistance, power absorbed and figure of merit.

Regarding the effects of engine and plane performance on radiator performance, the equation mentioned can also be used, with the aid of meteorological data, to estimate the performance of the radiator and the frontal area required, under varying conditions such as maximum rate of climb or level flight at all altitudes, if enough is known about the performance of the engine and of the airplane to determine the flying speed, the rate at which heat must be dissipated and the lift-drag ratio of the airplane, under the different conditions.

APPROXIMATE AIR TEMPERATURE VARIATION WITH ALTITUDE

Altitude in Ft	Ground	2,000	4,000	6,000	8,000	10,000	15,000	20,000	25,000
					Summer				
°C	38	36	33	30	27	23	14	—4	—6
					Winter				
°C	6	1	—2		—5.5	—8	—16.5	—26.5	—37

Cooling Systems

The following general notes were prepared for the guidance of airplane designers by the Engineering Division of the U. S. Air Service.* They are based on practical considerations of ease of maintenance, efficiency, etc.

Operating Conditions.—The most severe condition under which an airplane cooling system is called upon to operate exists during the maximum power output when the air speed is lowest and the air temperature highest. In most types of service airplanes, this condition coincides with full throttle maximum climb, full load, and ground temperature of 38 degrees Centigrade (100 degrees Fahrenheit). Standard air temperature conditions to be provided for are as follows:

General Design.—Wherever possible the cooling element should be designed to facilitate subsequent changes in size in order to give the airplane a wide range of cooling performance should this be found desirable.

Air Flow.—Other things being equal, the effectiveness of a cooling element (radiator core) varies with the mass flow of air through it; therefore, any obstructions to the greatest possible air flow should be avoided. The rate of heat dissipation by the cooling element should be figured on a basis of this air flow during the maximum climb above referred to. When nose radiators are used well-designed cowl louvres, having an effective area ten per cent greater than the free air area of the radiator core, are desired.

Water Flow.—Water passages should provide for ample water flow with minimum pump suction. In ribbon type cores a single restriction affects the entire passage between the headers. Where a water passage is designed exceedingly small, serious subsequent restrictions may occur from careless

* "Handbook of Instructions for Airplane Designers," Engineering Division, U. S. Air Service, McCook Field, Dayton, Ohio, 1922.

manufacture, rough handling, solder, variations in metal thickness, lime deposits, etc. Restricted water flow increases the temperature rise through the engine, causes cavitation and overflow, and lowers the boiling point owing to the increased suction produced by the pump.

Cooling Surface.—Direct cooling surface (surface backed by flowing water) is more effective, particularly at high air speeds, than indirect; however, when the radiating fins are relatively small and the thermal bond between them and the direct cooling surface is good, their loss in rate of heat dissipation over direct surface may be less than ten per cent. Stagnant water in the cooling element should be avoided. Where radiators are placed below, or below and in rear of engines with underneath carburetors, suitable allowance must be made for the blanketing effect of these carburetors and their induction pipes. Suitable allowance must be made for any structure effecting air flow through the core.

Temperature Control.—A positive, quick operating temperature control should be provided. At low air temperature a seemingly negligible air flow through the cooling element really produces a very considerable cooling effect. In systems adequate for summer flying this effect is magnified and may even interfere with performance.

Repair.—All parts of an airplane cooling system are subjected to severe shocks, strains, and constant vibration, and require suitable protection therefrom. Every design should facilitate field repair of all possible leaks. Internal seams and soldered joints not easily accessible must be avoided.

The following table of cooling system weights has been estimated and is included for the information of the designer:

ESTIMATED COOLING SYSTEM WEIGHTS*

Purpose and Engine	Model	R. P. M. Normal	Sea Level B.Hp	Weight of the Radiator and Water Tanks, Full, Lb.
(1)	(2)	(3)	(4)	(5)
Training				
Curtiss	OX5	1400	90	75
Wright	I and E2	1700	190	110
Pursuit				
Curtiss	D12	2200	430	160
Curtiss	V-1400	2100	500	195
Packard	IA-1500	2100	510	215
Wright	T3	2000	630	250
Observation				
Liberty	12A	1700	420	190
Liberty (Supercharged)		1700	420	250
Packard	IA 1500	2100	510	245
Packard	IA-2500	2000	800	380
Wright	T3	2000	630	285
Bombing				

(For slow bombing airplanes add 10 per cent to cooling system weights given for Observation airplanes, except where supercharger is used, then add 6 per cent to weight given for supercharged engine.)

Note: Column (5) includes radiator and radiator water, reserve tankage, and reserve

water only. Piping, water in piping, water in engine, and temperature control device are not included.

These estimates are based on adequate cooling with ground temperature 38° C. (100° F.)

* Table taken from Handbook of Instruction for Airplane Designers, issued by the Engineering Division, Air Service, 1925 edition.

Performance.—The cooling system shall operate satisfactorily, and the water shall not boil or exceed a temperature of 95 degrees Centigrade (203 degrees Fahrenheit) when the airplane is carrying full load at full throttle, maximum climb, from sea level to 7,000 feet altitude, with engine water not less than 60 degrees Centigrade (140 degrees Fahrenheit) at take-off and with a ground temperature of not less than 38 degrees Centigrade (100 degrees Fahrenheit). With this same ground temperature at maximum engine speed, level flight, below 1,000 feet the water in the system shall remain below 95 degrees Centigrade and shall not overflow.

Radiators.—Each radiator shall be of approved design and proof against the action of normal vibration. The total outlet area of each radiator shall be not less than the total inlet area of the engine water pump. Each radiator shall withstand, without leakage, an internal pressure of ten pounds per square inch, plus the pressure of the water carried in the system above the radiator. Each radiator shall be suitably protected against any collapsing due to the maximum pump suction possible in the system during specified performance.

(a) Radiating Surfaces—Radiating surfaces shall be clean, free from paint or any foreign matter, and polished. Each radiator shall be free from loose solder, acid, or other chemicals injurious to the metals of the cooling system.

(b) Radiator Shell—All joints and seams in the radiator shell shall be locked and soldered, or riveted and soldered All radiator shell areas four inches square or larger should be corrugated or otherwise stiffened to prevent undue distortion under service conditions.

(c) Each radiator shall be provided with a lip around the edges of the core extending out two inches from the core face, or if shutters are used immediately in front of the core, the lip shall extend to the plane of the closed shutters. This lip may be incorporated in the shutter frame if desired. Except where properly reinforced by headers, the radiator shell shall be turned in toward the core and back approximately parallel to itself, forming a "U" shaped cross section at the front and rear faces of the core. This portion of the shell must not act as a bypass for the water, nor shall it contain any water which does not drain coincident with the entire system.

(d) Flow Capacity—Under a pressure equal to the available head plus one pound per square inch, each radiator shall circulate an amount of water equal to that which the pump will deliver through the engine at normal speed. (The available head corresponds to a column of water whose height is equal to the vertical distance from the center of the water pump inlet to the point of overflow in the system, with the airplane in level flight position.)

(e) Radiator Protection—Where radiators are located in the lower wing or near the landing gear, suitable protection shall be provided against mud, dirt, and stones thrown back by the wheels or propeller.

(f) Radiator Mounting—Unless otherwise specified, all radiators must be strapped into padded cradles or mounted in a similar manner without supporting lugs or brackets being secured directly to the radiators themselves. Each radiator shall be so supported that movements due to expansion and contraction shall not be unduly restricted. Approved shock absorbing pads or cushions shall be provided between the radiator and its main supports. The radiator shall not be supported on or by the engine, or secured to it, except through necessary hose or flexible pipe connections. All radiators must be readily removable.

(g) Nose Radiators—Nose radiators shall be so constructed that they are removable over the propeller hub.

Temperature Control.—The system of temperature control provided shall be such that the temperature of the water in the system may be conveniently maintained above freezing and the temperature of the water in the engine at not less than 60 degrees Centigrade (140 degrees Fahrenheit) during indefinite flight, at the service ceiling of the airplane in December, anywhere within the United States. The temperature controls shall be simple, rugged, positive in action, and so placed that the pilot can operate them quickly and conveniently.

(a) Shutters—Each nonretractible radiator shall be provided with a strong, durable, well-designed shutter covering of the entire frontal area of the core when closed, and, if mounted in the rear of the propeller, shall be removable over the propeller hub. Where shutter vanes are used they must lap when closed. Each shutter shall be provided with an easily-operated positive control, convenient to the pilot, the control opening the shutter with a forward motion. Control design shall be such as to provide easy operation with a heavily gloved hand. Unless otherwise specified, shutters shall be operated by one of the following means:

I. Push and pull rods or tubes.
II. Torsion rods or tubes.
III. Suitable cables and pulleys.
IV. Combinations of I, II, and III.

Where pulleys are used for changes in cable direction greater than 60 degrees, their minimum grooved diameters shall be not less than 25 times the diameter of the cable used. Cable guides or runners exposed to the weather shall not be used. The open and closed control stops shall be at the shutter. Provision shall be made for the automatic opening during flight of each shutter should the controls break or become disconnected. Unless otherwise specified, each shutter vane, taken as an aerofoil at an angle of incidence of approximately 45 degrees, shall be pivoted at its center of pressure. Shutters will not be accepted with vanes or air deflecting elements so pivoted or mounted as to cause undue stresses on the control mechanism in any position throughout the range of operation during flight. The shutter and shutter controls shall be of rugged construction throughout.

(b) Shutter Mountings—Shutters shall be suitably attached either to the radiator itself or a suitable adjacent structure, but never to both. Shutters or shutter mountings attached to the engine will not be accepted. Where radiators, shutters, mountings, or controls are placed near a propeller,

the minimum allowable clearance between these and the propeller or propeller hub assembly shall be 3/4 inch up to and including fifteen inches from the axis of the propeller shaft, and one inch from this point up to and including 36 inches from the axis of the propeller shaft.

Expansion and Auxiliary Water Tanks.—Each expansion and auxiliary water tank shall be suitably mounted and protected against vibration and expansion strains. All auxiliary tanks shall be so protected as to prevent water freezing under all flying conditions. The water in all auxiliary tanks shall be in direct circulation with the cooling system unless otherwise specified. Each tank shall be clean and free from loose solder and all injurious acids or chemicals. Areas four inches square or larger shall be corrugated or otherwise stiffened to prevent undue distortion under service conditions.

Piping and Connections.—All piping shall be as direct as possible and free from sharp bends and restrictions. Cross sectional areas smaller than areas of corresponding ports in pump or engine will be considered restrictions. The inside radius of all bends shall exceed 2½ pipe diameters.

(a) Air Locks—All piping shall be free from possible air locks (high, unvented points) with the airplane in normal positions.

(b) Material—Piping shall be of metal wherever possible.

(c) Hose Connections—Rubber or fabric hose more than two diameters long shall be suitably reinforced to withstand, without distortion, an external pressure of fifteen pounds per square inch.

(d) Accessibility—All pipe and hose connections shall be readily accessible.

(e) Markings—All water piping shall be marked with a white band near each union and on each side of every flexible connection.

(f) Flexible Joints—Flexible joints shall be provided near all brazed joints and unions. All hose clamps used shall be of approved type.

Carburetor Manifold Jackets.—Provision shall be made for the best possible water flow through carburetor manifold jackets where these are provided. Water outlets from these jackets must be located in the line between the radiator and engine pump, preferably near the pump. Water discharge from these jackets shall not be near water thermometer bulbs.

Thermometers.—Each cooling system shall be provided with an approved type of thermometer which shall correctly indicate the temperature of the hottest engine water at all engine speeds. This thermometer shall be located in the circulating water, near the highest point, or directly above the engine.

(a) Location—All water thermometers shall be so located as to be unaffected by local temperature conditions such as water discharge from inlet manifold jackets, direct heat radiation from engine, exhaust gases, air traps, stagnant water, air flow, etc.

(b) Mounting—The bulbs of all water thermometers shall be not less than 75 per cent immersed in freely circulating water at engine idling speeds, and at the same time there shall be no undue restriction to water flow at these points.

Entire System.—Suitable provision shall be made against the possibility of dangerous steam pressures under adverse cooling conditions. In open systems the size of the vents shall correspond to their length and the capacity of the systems. All systems shall be completely vented to prevent

air locks, and in all closed systems where vents are necessary to prevent such air locks during filling, these vents, free from water traps, shall lead to the highest point in the filler necks. All parts of the entire cooling system must be suitably protected against corrosion.

(a) Closed Systems—At the highest point of each closed (pressure) system an approved safety valve shall be provided, as well as a suitable pressure gauge and a means of venting the system at will, convenient to the pilot.

(b) Vents—Vents shall be independent of filler caps. Vents and overflows shall not be susceptible to syphon action and shall not have pockets which will trap water. Unless otherwise specified, minimum vent sizes shall be as follows:

MINIMUM VENT SIZE

Engine Hp.	0 to 400	401 to 600	601 to 800	801 to 1000
Minimum Vent Diameter	⅛ in		⅝ ins	¾ in.

(c) Vent Location—Wherever water may overflow, the outlet shall be so located as to be visible from the pilot's seat, protected against freezing during flight at low air temperatures and against the excessive loss of water during dives. All outlets shall be so placed that water discharged therefrom can not interfere with the pilot or observer, or the proper functioning of any part or accessory of the airplane.

(d) Protection from Freezing—All water connected with the cooling system and not in actual circulation at engine idling speeds shall be suitably protected against freezing during flight at low air temperatures.

(e) Water Reserve—The system shall carry sufficient water to provide satisfactory cooling during a period equal to the fuel capacity of the airplane at normal engine speeds. Provision shall be made for using all reserve water before the level of the water in the system falls below the radiator core or the engine jacket outlets. The following formula is given as a guide in estimating the required amount of reserve water in open systems:

$$C = 10 + \frac{HN}{160}$$

C = Capacity required for reserve water in pounds.
H = Capacity of fuel tanks in flight hours.
N = Normal brake-horsepower of engine.

Provision shall be made for a head not less than two inches above the top of every cylinder jacket, with the airplane climbing at 25 per cent to the horizontal, or gliding at fifteen per cent, having a ten per cent list to either side, when all reserve water has boiled or leaked away.

(f) Filler Caps—Each system shall be provided at its highest point (tail skid on the ground) with a suitable filler cap forming a water-tight joint, and each cap shall be provided with a chain or other suitable attachment. The minimum inside diameter of all filler holes shall be not less than 1¾ inches. Durable filler caps, not requiring removal of cowling or other structure or the use of wrenches or special tools for removing shall be used.

Vents shall be independent of filler caps.

(g) Drain Plugs—Each system shall be provided at its lowest point (tail skid on the ground) with a suitable drain plug enabling the entire system to be quickly, easily and completely drained. Suitable arrangement shall provide against all possible injury to the airplane or its accessories from the discharge of this drain water. The minimum drain plug diameter shall be one inch. Each drain plug shall be suitably safetied against loosening. Provision shall be made for conveniently draining the engine water pump.

Engine Installation

The United States Air Service has drawn up general instructions for the installation of airplane engines based on practical considerations such as safety, ease of maintenance, etc. Airplanes submitted to the Air Service are required to comply with these specifications. The following is abstracted from the "Handbook of Instructions for Airplane Designers" issued in 1922 by the Engineering Division, McCook Field, Dayton, Ohio.

Engine Mounting.—The engine mounting shall be so designed as to afford the maximum strength and accessibility consistent with the general design of the airplane. Attention is particularly directed to the fact that eight-cylinder, 90 degree, Vee-type engines have a decided tendency to vibrate in a horizontal plane, and suitable precaution to stiffen the structure against this vibration shall be taken. It should also be noted that the extreme rigidity in the immediate vicinity of the engine is of little value unless proper provision is made to carry this strength through to the main points of support. The engine should not be used to support any part of the airplane structure or any accessory not forming a part of the engine equipment. (The frames shown at Figs. 747 and 748 are well braced to withstand vibration of eight-cylinder engines.)

(a) Removal of Engine—The engine shall be so mounted in the airplane that it can be readily removed as a unit without detaching magnetos, water pump, carburetors, or any accessory which is properly a part of the engine, or removing any important parts of the airplane structure. The time required to remove the engine should not exceed four hours.

(b) Holding Down Bolt—The engine holding down bolts shall be of a size to fit the holes in the engine feet with a clearance of not over $\frac{1}{32}$ inch. Large washers shall be provided to prevent the bolt heads crushing the engine bearers. These washers shall be $\frac{1}{2}$ inch larger diameter than the standard washers for bolt used.

(c) Engine Support—A steel strap of approximately $\frac{1}{16}$ inch in thickness shall be securely fastened to the engine bearer at points of engine support. These straps shall be of greater width than the engine feet, except in cases where engine feet are continuous, in which case lighter sheet metal may be used to protect the engine bearer face.

(d) Magnetos—It shall be possible to remove the magnetos or other ignition devices from the engine as an entire unit without detaching any other part. It shall be possible to clean and adjust the breaker points without removing the magneto from the engine. The breaker points shall be directly visible without moving the magneto or removing any other part.

(e) Distributor—It shall be possible to inspect and clean the distributor without disconnecting any high tension wire or removing any other part

of the airplane engine, or equipment except cowling.

(f) Carburetors—No part of the airplane structure or equipment shall be so located as to necessitate its removal in order to remove the carburetor from the engine or to interfere with the accessibility of the float chamber, carburetor strainer, and jets.

(g) Water Pump—It shall be possible to remove the water pump from the engine as an entire unit without removing the engine from the airplane. The water pump shaft packing shall be easily accessible for adjustment.

(h) Oil Strainer and Relief Valve—No part of the airplane structure or equipment shall be so located as to interfere with the accessibility of the oil strainers and relief valve on the engine.

(i) Oil Pump—It shall be possible to easily remove the oil pumps without moving the engine, tanks, or important parts of the airplane structure.

(j) Fuel Pump—If a gasoline pump is mounted on the engine, it shall be possible to easily remove this pump without moving the engine, tank, or important parts of the airplane structure.

(k) Starter—If the engine is equipped with a starter, it shall be possible to easily remove the starter without moving the engine, tanks, or important parts of the airplane structure.

Engine Controls

Care should be exercised to insure an engine control installation that is simple, reliable and convenient.

Operation.—Controls shall be operated by rods, torsion members, or flexible cable. Rods or torsion members are greatly preferred, and flexible cable should be used only where unavoidable. If flexible cables are used, pulleys shall be provided at all points where the direction of the cable is altered. Flexible cable run through tubes or flexible sheathing will not be permitted. Controls shall be positively operated, and springs shall not be relied upon to actuate the control in either direction. All controls shall be of the friction type so designed that frequent adjustment will not be required.

Stops.—Stops limiting the motion of the control shall be located at the control lever. All levers shall be so installed that the normal motion of the engine control is not reduced, and when the control handle is against the stop, the corresponding control lever on the engine shall be against its stop.

Direction of Motion.—All engine controls shall move forward for the open or running position; that is, the throttle handle must move forward to open the throttle, the mixture control handle shall move forward to make the mixture lean, the spark control handle shall move forward to advance the spark, the shutter control handle shall move forward to open the shutter and the supercharger blast gate lever shall move forward to close the blast gate, thereby bringing the supercharger into action.

Marking.—All engine controls shall be clearly marked as follows: the throttle control lever shall be marked "Throttle," the extreme positions shall be marked "Open" and "Closed"; the mixture control lever shall be marked "Mixture," and the extreme positions shall be marked "Rich" and "Lean"; the spark control lever shall be marked "Spark," and the extreme positions shall be marked "Retard" and "Advance"; the shutter control lever shall be marked "Shutter," and the extreme positions shall be marked

"Open" and "Closed"; the supercharger blast gate lever shall be marked "Blast Gate," and the extreme positions shall be marked "Open" and "Closed." In marking the control levers the abbreviations "T," "M," "B," and "S" may be used for the throttle, mixture, blast gate, and the spark levers, respectively.

Disposition.—In airplanes intended to be operated by two pilots, such as training airplanes, the engine controls shall be so arranged that either pilot may have complete control. In training airplanes the spark, throttle and mixture controls shall be installed for both pilot and student. The gasoline shut-off valve, ignition switch, and shutter control need not be duplicated, but must be so installed that they can be conveniently operated by either pilot or student. The primer, booster magneto and starter switch shall be installed in the rear cockpit only. The throttle and mixture controls only, need be installed in the gunner's or observer's cockpit in two-seater service types.

Location.—In single-engined airplanes the throttle, mixture, and spark controls shall be conveniently located at the left-hand side of the pilot. The location of the shutter control shall be such that it may be conveniently reached by the pilot, the left-hand side being preferred if a convenient arrangement can be secured. Where two or more engines are used, the control system shall be so arranged that the engines may be controlled individually and simultaneously. The location of the control levers should, as far as possible, follow the requirements laid down for single-engined airplanes.

Switch Location.—It is preferred that the ignition switch be located conveniently to the pilot's left hand, especially on service airplanes.

Lubricating System

Capacity.—The lubricating oil tank capacity in general, shall be not less than $\frac{1}{10}$ of the gasoline capacity by volume.

Expansion Space.—An expansion space equal to ten per cent of the tank capacity, to provide for the increase in volume of oil due to expansion and the inclusion of air bubbles in the oil returned from the engine sump, shall be provided in each lubricating oil tank.

Tank Location.—The tank shall be located as near the engine oil pump as possible and shall be approximately on the same level as the pump inlet. In case the Liberty engine is used, the bottom of the oil tank shall not be below the pump inlet.

Filler Location.—The location of the oil tank filler opening shall be such as to facilitate filling the tank without the use of a special funnel. It is desirable that the filler opening be accessible from outside the airplane, either by allowing the filler neck to project through the side wall or by having a properly covered opening in the side wall near the filler opening. The location of the filler opening shall be such that oil overflowing will not fall on parts of the airplane structure or engine accessories which might be damaged. The filler opening shall be so arranged that it is impossible to fill the expansion space, with the airplane in normal position on the ground.

Vents.—All oil tanks shall be provided with vent tubes of $\frac{1}{2}$ inch outside diameter. These vent tubes shall be so located as to prevent the

pocketing of air in the oil tank, and shall be connected to the engine crankcase on all engines provided with the necessary opening. Where it is not possible to connect these vents to the engine or crankcase, they shall be led to a point where oil overflowing will clear all parts of the airplane.

Pipes.—All oil pipes shall be of annealed copper tubing with a wall thickness of approximately $\frac{1}{32}$ inch. The diameter of the oil pipes shall be not less than that of the connections on the engine. The oil pipes shall be as short and direct as possible. All oil pipes shall be lagged by wrapping with cord or fabric tape where exposed to a direct air blast. Soldered, welded, or brazed joints will not be permitted in oil lines.

Connections.—All oil pipe connections shall be made with fabricated rubber hose and approved type hose clamps. The ends of the pipes shall be beaded to prevent the hose from slipping off. The length of exposed rubber hose at a joint shall not exceed the inside diameter of the hose. The proper method of making up an oil pipe connection is illustrated in Fig. 751.

Cooling.—The lubricating oil tank shall be provided with sufficient cooling area to keep the temperature of the oil below 70 degrees Centigrade under all conditions of flight. This may be accomplished by providing a separate oil radiator, or preferably, by making part of the oil supply tank serve as an oil cooler. The oil cooling elements must not contain restricted passages which would offer undue resistance to the flow of cold oil.

Strainers.—Oil strainers, other than those contained in the engine, are not to be used.

Circulation.—In order to assist in cooling the oil, the oil piping shall be so arranged that oil will circulate through the entire tank.

Drain Plug.—A drain plug not smaller than a $\frac{3}{4}$-inch pipe plug shall be provided. The location of this drain plug shall be such that it is readily accessible and that the entire contents of the lubricating system may be drained. Means shall be provided for locking this plug.

Tank Connections.—Connections to the oil tank shall be made by means of standard pipe flanges and nipples or elbows.

Cowling

General Arrangement.—The cowling around the engine shall be constructed with a view to securing minimum head resistance, protection to the engine, the crew and airplane structure from fire in the engine compartment.

Air Flow.—The cowling shall be provided with suitable air inlets and outlets to allow ample flow of air over and around the engine sump and cylinders. In case a nose radiator is used the air outlets shall be so arranged as to allow ample flow of air through the radiator. The effective area of these outlets shall exceed by not less than ten per cent the free air area of the radiator core. When a Wright engine is used, it is desirable for the valve covers to project through the cowling. This assists materially in cooling the engine.

Attachment and Support.—The cowling shall be attached to its supports by means of removable hinge pins, thumb nuts, flexible cable with turnbuckle, or other approved device. Attaching devices of elaborate design or difficult to obtain shall not be used. The cowling supports shall be entirely independent of the engine, and care shall be taken to see that engine

vibration is not transmitted to the cowl, as this greatly decreases the life of the material. All cowling shall be quickly and easily detachable.

Doors.—Properly secured doors shall be provided which will permit access to the engine for adjustment, whenever necessary. These doors shall be marked clearly, indicating the parts to which they give access.

Propeller Clearance.—The clearance between the engine or radiator cowling and the propeller shall be not less than ¾ inch at all points within a radius of fifteen inches from the center of the shaft and not less than one inch at all points within a radius between 15 and 36 inches.

Ignition—Arrangement of Wiring.—The installation of the ignition wiring shall be carefully considered and every effort made to guard against the possibility of grounded, open, or short circuits. Carelessly installed wiring is a constant source of danger and may incur both engine failure and fire. The wiring shall be simple, direct, and accessible. All unnecessary slackness shall be avoided and the wires installed and supported in a neat, workman-like manner. All wires shall be run in a group, and so located that danger of oil, water, or gasoline dripping on them is avoided. As far as is consistent with the above, the wires shall be as accessible as possible for inspection and replacement.

Wire.—Each wire shall be continuous from end to end, no splices being allowed.

Protection of Wiring.—Great care shall be exercised to guard against chafing of the insulation The use of aluminum or fiber conduits is desirable where possible Where wires supported by metal clips and passing through the fire wall or bulkheads are apt to rub against any wooden or metallic parts, they shall be protected by fiber or rubber grommets or other acceptable device. Particular care in this regard shall be taken with high tension wires.

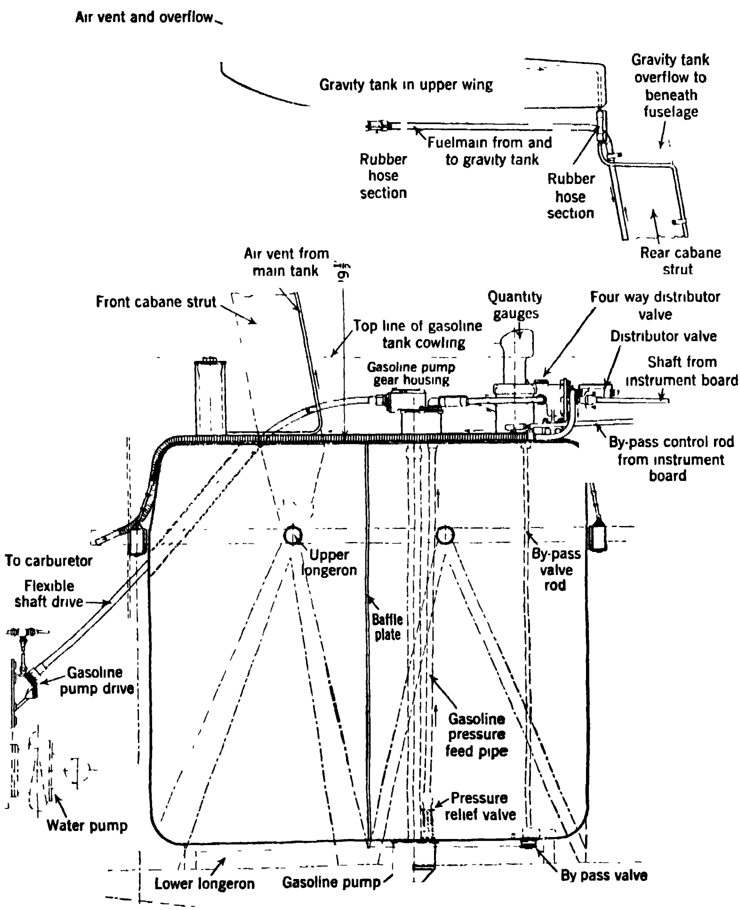
Ground Wire.—The ground wire shall be connected with the engine itself and not with any part of the engine mounting or airplane structure.

Storage Battery.—The storage battery shall be carefully housed, supported, and protected against oil, gasoline, and water. It shall be so located that in case a cell is broken the acid will not injure any vital part of the airplane.

Booster Magneto.—If a booster magneto is installed, its location shall be such that the handle is not apt to be accidentally struck during operation of the airplane or while climbing in or out of cockpits. The location shall also be such that there is no danger of fuel leaking on the magneto or of sparks passing between the magneto and metallic parts of the airplane.

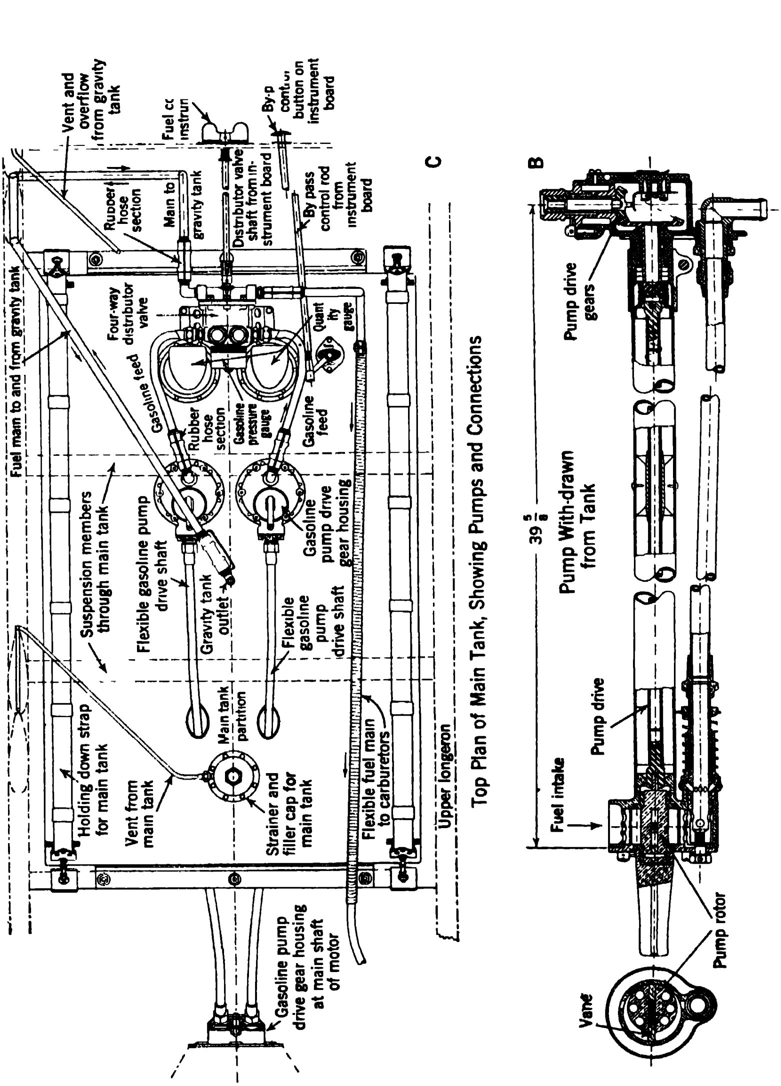
McCook Field Gasoline System.—A special gasoline system developed at McCook Field, and known as the McCook Field Gasoline System, has been used in the USD-9A now obsolescent. In this system, there is no pressure in the supply tanks other than that of the atmosphere, although the pumps provide positive force feed to the carburetors. One of the considerations was to provide as large a tank capacity as possible with a minimum weight of the elements involved. It was also the aim to minimize the fire danger from leakage of fuel, and to incorporate a reserve supply system sufficient for about 25 miles of flight with full accessibility of the reserve fuel. In addition, the desira-

bility of providing a positive gravity feed at starting was recognized. Briefly, the system which is shown at Fig. 751 A consists principally of a main supply tank of 134 gallons capacity with feed to the carburetors by means of two vane gasoline force pumps, driven from the crankshaft by flexible shafting, and an eight gallon gravity tank, located in the center section of the upper wing span. It should be noted that whereas the pump arrangement affords positive feed under all conditions, no air pressure is utilized in the fuel system as was used in the old De Havilland with Liberty motor. The total fuel supply of 142 gallons is sufficient for about four hours operation of the Liberty-12 engine



Layout of Gasoline Feed System Incorporating Main Pressure Tank and Overhead Gravity Tank

Fig. 751A.—Layout of McCook Field DH9 Gasoline System Which Used Two Vane Type Pumps at Bottom of Main Fuel Tank Driven by Flexible Shaft Connection with the Engine.



Figs. 751 B and C.—Sectional View of Fuel Pump for Installation in Fuel Tank Used with McCook Field Gasoline System at B Shows Construction of Pump and Drive. Plan at C is Top of Main T. Showing Pumps and Connections. Also Control Valve.

at full throttle, and at ground-level rate of consumption.

The main tank was 38 inches long, 34½ inches high and 23¾ inches wide, with its forward face five inches to the rear of the extreme end of the engine. The gravity tank measured 32¾ inches in length, 13¾ inches in width, and was 5½ inches maximum depth. The curvature of the bottom of this tank is such as to insure drainage of its entire contents to the carburetor, while the plane is at any normal angle of flight. The large rectangular main tank is constructed of sheet steel, with riveted and soldered joints, and is divided longitudinally by a partition and transversely by a baffle plate.

Tank Locations and Supports.—The main tank is located in the fuselage back of the engine and booster radiator, and forward of the pilot's cockpit. This position is as close as possible to the center of gravity of the plane, so that the stability will not be appreciably altered by the consumption of the 842 pounds of fuel carried. The tank rests on padded longitudinals carried by cross struts between the lower fuselage longerons, and is held securely in place by holding-down straps attached to cross struts between the upper longerons immediately ahead of and behind the tank. The overhead gravity tank is supported by metal brackets on its under side from the front and rear spars of the center wing section. The convex bottom of the gravity tank projects below the under side of the center section, and at its lowest point is about 29½ inches above the top surface of the main tank.

The feed pipe connection between the main tank and the gravity tank is carried upwards from the gasoline pump through a four-way control valve along the right rear cabane strut, into which it is inset along the entering edge. When this pipe reaches approximately the height of the curved bottom of the gravity tank, it is carried forward on a level to the entry point. Surplus gasoline reaching the gravity tank overflows through a smaller pipe which is brought down along the trailing edge of the same rear cabane strut, and which serves as a combination vent and overflow pipe

Tank Vents.—Venting of the gravity and main tanks is provided for by means of small-diameter tubing. In the case of the main tank, vapor only may be discharged, and for this purpose a pipe runs from the base of the filling pipe to the rear edge of the forward cabane strut, up which it is carried for some distance into the full sweep of air from the slipstream. The gravity tank vent ends within the reservoir just at the filler cap, and is carried down the trailing edge of the right rear cabane strut to a point beneath the level of the fuselage, where both vapor and excess pumped fuel are discharged into the open air, far enough away from the engine to remove any fire danger from this cause.

The top of the main tank shown at Fig. 751 C carries the filler neck, cap and strainer, which assembly is placed 5¾ inches to the rear of the forward face of the tank. The filler cap is approximately 7¼ inches above the surface of the tank at a level of the top cowling and closes a 2¼ inch tube extension from the tank proper. Also on the top of the tank are the housed pump gears, gauges and four-way distributor valve. The gauges are enclosed in small streamlined housings, and project ten inches above the tank which brings them 2¾ inches above the fuselage top cowling. Between the two gauges which indicate the fuel level in the left and right chambers of the tank, is a gauge which shows clearly the amount of pressure on the force-feed line in pounds. Due to their height and location, these three gauges are visible and easily read by the pilot through the windshield in front of his cockpit. The four-way control valve is located on top of the tank just back of the gauges, and is connected by means of a control shaft to an operating handle on the instrument board. The four-way valve has three working positions and an "off" position. At starting, the valve is so turned that the main tank gasoline supply is shut off, and the carburetors receive fuel from the overhead tank through the supply pipe and the four-way valve.

When the engine is running at sufficient speed to operate the fuel pumps

at full pressure, the control valve may be turned to the running position, so as to send the fuel from both main tanks direct to the carburetors. With the valve in this position the gravity tank is shut off entirely from the rest of the system, holding its contents in reserve. If it is desired to fill the gravity tank when the engine is running the four-way valve may be turned to its third running position, in which case fuel will be pumped to the carburetors and to the overhead tank as well as from the main tank. It is also possible to fill the gravity tank through a filler opening provided for use when the plane is on the ground and the engine not operating.

Gasoline Pump Drive.—From the bevel gear attached by studs to the rear end of the mainshaft of the Liberty engine, by which the engine water and oil pumps and the camshafts and generator are driven, there are two spline-driven flexible-shaft drives at the right and left sides of the centerline of the engine, which lead upward and backward at an angle of about 45 degrees through flexible tubing inserted at that angle through tunnels in the upper front corner of the main tank, and terminate at reducing bevel-gear drives on the tank, which operate the vertical gasoline-pump shafts, at about one-third engine speed. These duplicate bevel gears are housed, and the shafts penetrate the tank to wells at the bottom in which the vane-type rotary gasoline pumps are located. From each gasoline pump upwards there is a suitable pipe which carries the pumped fuel to the four-way valve. Beneath the pump well is a cap which gives access to the tank for drainage purposes.

The construction of the vane gasoline pumps is shown in Figs. 751 A and 751 B the latter showing the bevel-gear drive in the housing B on the top of the main tank. This bevel gearing actuates a shaft C in a tube D, which has a bearing E midway along the length of the shaft. The shaft terminates at F, where it engages a rotating barrel G in the pump housing H, of which the power portion I is seated in the well at the bottom of the tank. Housing H has a strainer J which leads to holes K giving entry to the pump pressure chamber. The rotating barrel G has a slot through it in which are two vanes N held apart by a rotating spring M. The parts N work in the eccentrically-placed pumping chamber L, and by acting as vanes, drive out all pumped fuel through the discharge openings O to the pressure-discharge pipe P.

Around P are a sliding sleeve and adjustable holding-down spring Q which work over the housing and close the holes R through the pipe P. It will be noted that the sleeve Q seats on a tapered shoulder in which the holes R are drilled at an upward angle, so that the gasoline under pressure in the discharge tube P tends to lift the sleeve Q off its seat. This tendency is counteracted, however, by the outside pressure on the sleeve Q due to the weight of the gasoline in the tank, as well as by the holding down spring. The amount of pressure necessary to raise the relief valve off its seat will therefore vary according to the amount of fuel in the main tank at any time.

The moment the gasoline pressure reaches a set value, such as four pounds per square inch for a full tank to 1½ pounds per square inch for a low fuel head, sleeve Q is raised and the surplus fuel passes out through the relief opening formed by the passage then available at R. The surplus fuel then returns automatically to the supply tank, in which the entire assembly is submerged at all times. Gasoline is forced from each pump, under 1½ to four pounds pressure, through individual gravity-seated check valves to the distributor or four-

way valve. The check valves prevent either pump discharging into the opposite side of the tank in case of failure of one of the pumps from any cause.

While this system has advantages and has been modified and modernized by the Stewart-Warner interests and others by using tank mounted electrically operated pumps, the weight of the pumps and piping is greater than that of the systems where the fuel pumps are mounted directly on the engine, which is the latest practice. This fuel pump is illustrated to show still another practical method of fuel supply in addition to the systems shown in various sections of this treatise.

Fuel System

Fuel Tanks.—All tanks shall be accessible for removal and repair and shall be carefully mounted to prevent damage from shocks, excessive vibration and weaving. Tanks must not be located to the rear of any member of the crew except in rare circumstances, such as in the case of armor plate separating the tank and crew. It should be possible to remove a tank from an airplane, which is in flying condition and install a new one complete in four hours. Vents of tanks shall be so located that the vapor or fuel which might come through them will not be in danger of catching fire or of blowing into the pilot's face. It shall be possible to drain tanks completely and quickly. An opening corresponding to a ½-inch pipe thread shall be used for tanks up to 100 gallons capacity and ¾-inch pipe thread for tanks of over that capacity. It is desirable to make it possible to attach a hose for draining the tank. If a tank is operated by gravity, the head of fuel on the carburetor float chamber shall be such that the engine will operate at full throttle when the airplane is at the steepest climb. The auxiliary gravity tank capacity shall be sufficient to operate the engine at full power for 20 to 30 minutes at sea level. The main tank shall have a hopper bottom which will allow the water in the fuel to drain through the tank outlet with the tail on the ground. The gravity tank shall be so constructed and installed that it will drain completely in either the steepest climb or at the best gliding angle.

Leakproof Tanks.—Leakproof tanks shall be provided on all airplanes for service use unless the tanks are completely protected by armor. It is undesirable, however, to have tanks located in an armored compartment or fuselage with the crew, even if leakproof. Leakproof tanks shall not be supported by brackets or lugs that are fastened directly to the tank walls. The support for these tanks shall consist of a "cradle" or "saddle" and the tanks shall be held firmly in position by straps or bands passing around the outside of the tank. The supporting areas of the cradle shall be of such size that the pressure on the bearing surfaces will not exceed eight pounds per square inch when the tank is full. The weight of leakproof tanks of 40 to 80 gallons capacity will be about 1 6 pounds per gallon of capacity or an average of 4.3 pounds per square foot of wall area. The walls of leakproof tanks will in general be from ⅛ inch to ¼ inch thick across the top and ½ inch to ⅝ inch thick on the sides and bottom. The tanks shall be regular in shape, without protuberances, re-entrant angles or sharp corners.

Crashproof Tanks.—Crashproof tanks shall be installed on all training airplanes. The support of the tanks in the airplane shall be as described

for leakproof tanks. The pressure on the bearing surfaces may, however, run as high as twelve pounds per square inch in crashproof tanks. The weight of a crashproof tank of 40 gallons capacity will be about 1.25 pounds per gallon. The walls of crashproof tanks shall average $\frac{1}{8}$ to $\frac{3}{16}$ inch in thickness. Tanks should be smooth and of regular shape.

A filler shall be provided on each tank in such position that the tank may be filled with the tail on the ground and from outside the airplane.

Tanks shall be so designed that they will withstand an inside pressure, without injury, in accordance with the following formula, with the exception that the minimum testing pressure shall be three pounds per square inch:

$$P = \frac{DF}{4} \text{ in which}$$

P = testing pressure in pounds per square inch.

D = Depth in feet of tank measured perpendicular to the propeller axis.

F = Load factor for fuselage static test.

Plain Tanks.—The material shall be tinned steel made in accordance with A. S. Specification No. 10,207. All seams, including those between the splash plates and the walls of the tanks, shall be riveted and soldered where possible. Copper or soft iron rivets shall be used throughout, the exposed parts of the rivets being tinned in case iron rivets are used

Leakproof Tanks.—Leakproof tanks shall be constructed in accordance with A. S. Specifications Nos. 28,300 and 16,025.

Crashproof Tanks.—Crashproof tanks shall be constructed in accordance with A. S. Specifications Nos. 28,302 and 16,033.

Piping and Connections.—The piping used in fuel systems shall be of seamless, annealed copper tubing, conforming to A. S. Specification No. 11,048, the size of which is to be determined by the following considerations:

(a) All vents shall be $\frac{1}{4}$ inch O. D.

(b) Primer tubing shall be $\frac{1}{8}$ inch O. D.

(c) Carburetor overflow drain lines shall be not less than $\frac{3}{8}$ inch O. D. up to 400 horsepower per carburetor. These lines must drain the bowls in any normal flight position.

(d) In the main lines when the flow is under 30 gallons per hour, tubing should be $\frac{3}{8}$ inch O. D.; between 30 and 60 gallons per hour, $\frac{1}{2}$ inch O. D.; between 60 and 100 gallons per hour, $\frac{5}{8}$ inch O. D.; and between 100 and 150 gallons per hour, $\frac{3}{4}$ inch O. D.

(e) Wall thickness shall be $\frac{1}{32}$ inch for $\frac{1}{4}$- and $\frac{3}{8}$-inch tubing, and $\frac{3}{64}$ inch for $\frac{1}{2}$-inch, $\frac{5}{8}$-inch and $\frac{3}{4}$-inch tubing. .025-inch wall is preferable for primer tubing.

(f) All tubing shall be well cleaned inside just before installation.

(g) All tubing shall be so mounted as to prevent vibration and chafing. This may be accomplished by proper use of clips. The tubing at clips and where touching other parts of the airplane shall be protected by tape, or equivalent, suitably applied.

All joints in fuel lines shall be made according to one or the other of the methods shown at Figs. 752 and if tube ends are joined by rubber hose,

the dimensions shown at Fig. 753 must be adhered to.

In the case of the union connection, hard silver solder must be used in securing the cone to the tubing. Some approved means of locking the nut shall be provided.

Care shall be taken to allow enough straight tubing near a flexible connection to permit the hose being slipped along the tube sufficiently to assure the easy insertion of the liner. Fuel tubing should never be beaded or flared. No tube shall be joined to another by brazing, welding, or soft soldering.

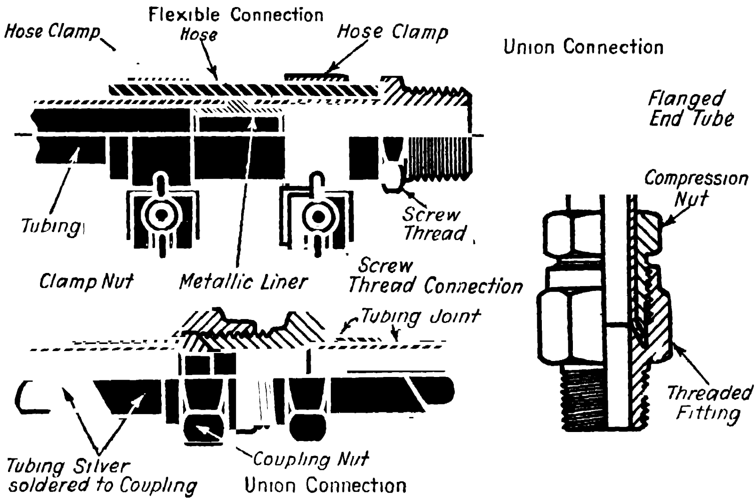


Fig. 752.—Various Types of Fuel Pipe Connections Used in Powerplant Installation.

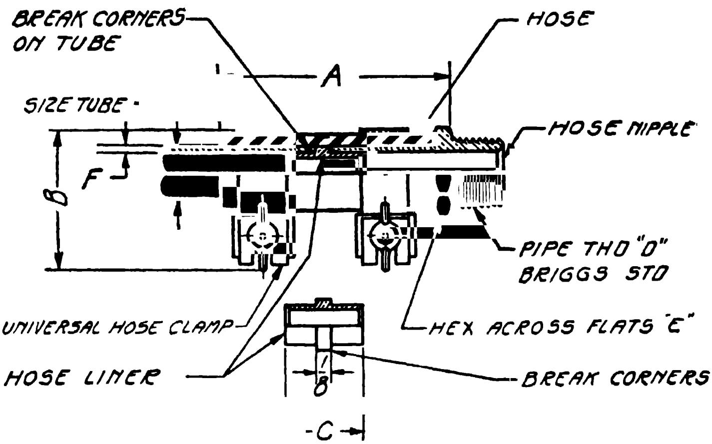
Strainers.—Unless the tank is provided with an approved water sump, the strainer must be so located and piped that it will act as a water sump for the tank, with the tail on the ground. The strainer shall be rigidly mounted and sufficient clearance allowed above it to permit the removal of the screen. Unless the strainer is incorporated in the carburetor, a suitable strainer in the carburetor inlet will be provided. These strainers must be readily accessible for cleaning.

Priming System.—A priming system shall be a part of every fuel system. The priming pump intake lines should be as short as possible and connected as shown on the typical fuel system previously described. The priming pump shall be so located as not to be under pressure when the engine is not running.

Carburetor Air Intakes.—Each carburetor shall be provided with an extended air intake pipe through which air can be drawn from outside the engine compartment. The outer end of the pipe shall be beveled 30 degrees to the propeller axis, sloping forward, the forward end of the bevel being about one inch beyond any obstruction to the air flow. The air intake pipe shall at no point be of smaller internal area than that provided in the connection at the carburetor. There shall be no openings whatever in the air intake pipe within the engine compartment. The joint between the pipe

and carburetor shall be gasoline tight.

Exhaust System.—The exhaust pipe or pipes shall be arranged so that exhaust gases are carried clear of the crew and do not discharge directly on any part of the airplane where the gasoline overflow could be ignited by them. The exhaust manifold shall always be outside of the cowl, never within it. If the exhaust manifold is supported by any part of the airplane structure, provision shall be made to prevent undue strains due to expansion. The inside radius of all bends in the exhaust pipe shall not be less than twice the diameter of the pipe. A clearance of 2½ inches at least shall be provided between the exhaust manifold and wooden parts of the airplane. Near fabric parts, the air space or clearance should never be less than 3½ inches. In case any wood or fabric parts are located directly behind the



LEXIBLE TYPE OF JOINT BETWEEN A FEMALE PIPE THREAD AND COPPER TUBING

Size Tube	Air Service Numbers			A	B	C	D	E	F
	Liner	Nipple	Hose						
¼	037703	037745	HG2761	2⅜	1	¾	⅛	7/16	1/32
⅜	037704	037720	HG2762	2⅜	1¼	¾	¼	⅝	1/32
½	058202	058198	HG2894	2⅝	1⅜	¾	⅜	¾	1/32
⅝	058203	058199	HG2393	2¾	1½	1⅛	½	⅞	1/32
¾	038143	038221	HG2224	1⅝	1¾	1⅛	¾	1¼	3/64

Air Service Approved Flexible Fuel Line Joint.

Fig. 753.—U. S. Air Service Approved Flexible Fuel Line Joint Between a Female Pipe Thread and Copper Tubing.

exhaust manifold, the clearance shall be increased to five inches. Exhaust manifolds which partially muffle the noise of the exhaust are desirable but should not be used if the functioning of the engine is in any way impaired.

Plumbing Troubles.—Commenting editorially on the subject of some flight failures that were the result of poor fuel or oil connections and not

of the engines themselves, *Aviation* points out that more attention to details of installation such as fuel, oil and water piping is necessary when airplanes are designed, commenting as follows:

"As a continuation of Atlantic flight attempts seems to be inevitable, one might as well take advantage of the situation and draw such conclusions as may be derived from analyzing the causes for the failure of the flights. Courtney's flight, Francos' flight and the Polish flight were all three terminated by what is popularly known as 'plumbing' trouble. In none of the instances cited was there any failure in the engines, but in all three cases the engines stopped through failure of the feed lines. The failure of Francos' four-engined Dornier plane was the most striking. Apparently all four engines quit at so nearly the same time that a hasty descent from a low altitude had to be made and the plane was very badly damaged. On investigation it was found that the gasoline pumping system had failed and apparently even the best of engines will not run without gasoline. It would seem as if this should have been realized before and that an independent pumping system should have been in operation for each engine. Working out a system where each engine is independent of the other, yet at the same time can use the gasoline of any other engine is not as simple as it sounds, but it certainly can be worked out.

"In the case of the Polish fliers the oil system failed, but as the plane was wrecked it may be hard to ascertain exactly what happened. Apparently the failure was not in the pumping system but in the piping system, as there was an evident and large leakage of oil. In the case of Captain Courtney the failure was due to the breaking of the main gasoline feed line. Evidently either the material used was faulty, or, what is more likely, it was so supported that it was subject to excessive strain and that failure was merely a question of time. In either case the danger of running gasoline lines through spaces enclosed by cowling and close to the exhaust was demonstrated.

"The arrangement of feed lines is not an exact science and the stresses involved are not as calculable as those on a wing or crankshaft, but none the less, it would seem as if enough experience had been gathered to prevent so many failures from such causes. Of course, all the planes in question were in a sense experimental and the particular installation had not been tested in the tens of thousands of miles of flying which standard types run up. It is evident, however, that the arrangement of the feed lines, especially for the new types of engines which are being brought out, is a matter which requires the greatest care, and it should not be left to the shop mechanic or even to most plane designers. To the flier the failure of a feed line is just as serious as the failure of a crankshaft, and if engine manufacturers care about the reputation of their product they should check carefully with the plane manufacturer the details of the engine accessories."

Causes of Airplane Accidents.—H. C. Dickinson, chief of the Heat and Power Division, Bureau of Standards, has described laboratory and service tests of engine safety. He enumerated five points which were chief contributing factors to accidents caused by powerplant failure: Mechanical or structural defects in the engine; failure of fuel supply; failure of ignition; failure of the lubricating system, and failure of the cooling system. Of

these, failure of the fuel supply and ignition are the most prolific of accident, with mechanical or structural defect coming second. Secondary causes of these accidents, due to a personal aspect, are carburetor control, control of engine speed—where pilots drive their own planes at top speed or above rated power—and carelessness in the choice of fuels.

Charles L. Lawrance, president of the Wright Aeronautical Corp., speaking on the safety requirements of an aircraft engine and its installation, has pointed out that the engine for successful aircraft use must be made to meet conditions far from the ideal. Careless mechanics will not oil all parts as they should be oiled and pilots may not use the correct grade of gasoline or oil. These are factors which enter into the operation of an aircraft motor which make it necessary to construct these motors with a high factor of safety. Engines must be designed and installed, he said, so that they will stand overloading, so that ice will not form in the carburetor under any conditions and so that all accessories will be easily accessible for maintenance purposes. Some of the features which he regards as necessary for a good aircraft motor are oil cleaners, protection of ignition wires, multiple valve springs, dual ignition and some method of preventing broken valves from falling into cylinders. These conditions are fully met by the latest designs of aviation engines.

In the two years and a quarter since by Act of Congress an Aeronautics Branch was established in the Department of Commerce the number of civilian-owned planes has risen from 2,200 to 8,500, and 16,008 original examinations for pilots have been certified, 3,688 pilots licensed, 1,650 candidates have made preliminary examinations, and 8,683 have received students' permits. In the exercise of its functions the Aeronautics Branch has surveyed and lighted approximately 8,000 miles of airways and has a program for completing 7,000 more. The total mileage in civilian airways is now 14,341 finished or planned, and there are 1,387 airports of all kinds. The branch has devised navigation aids, established flying rules, outlined standards for planes and equipment, and kept tabs on each flier's fitness for the air.

In efforts to decrease accidents and increase safety the Aeronautics Branch recently established an Accident Board, consisting of two pilots, one statistician, one flight surgeon, one aeronautical engineer and one lawyer, the intention being to apply specialized knowledge to each phase of the problem. The board takes and analyzes an accident for percentage of causes. These are treated under four general heads—personnel, material, miscellaneous, undetermined and doubtful. Under pilot (personnel) for the period from January 1 to July 1, 1928, there were five classifications of error for accidents due to the pilot. These were expressed in percentages: Error of judgment, 8.45; poor technique, 22.95; disobedience of orders, 4.95; carelessness or negligence, 6.32, and miscellaneous, .62, or a total of 43.29 per cent due to errors of pilot.

Under material, the accidents were classified as due to powerplant, structural, handling qualities and instruments. All these are broken down to other subheads. Under "powerplant" the board found cases traceable in the following percentages: Fuel system, 5.12; cooling system, .57; ignition system, 4; lubrication system, .13; engine structure, 1.29; propellers

and accessories, .44; engine control system, none; miscellaneous, .45; undetermined, 4.59, or a total of 16.59 per cent due to powerplant failures. Similarly, under "structural," the accidents were attributed in percentages as follows: Flight control system, .85; movable surfaces, .35; stabilizing surfaces, none; wing, struts and bracing, 1.09; undercarriage, 1.64; wheels, tires and brakes, .19; pontoons or boat, .03; fuselage, engine mount and fittings, .75; tail skid assembly, .19; miscellaneous, .23; undetermined, none, or a total of 5.32 per cent due to structural failures.

Handling qualities were given for .44 per cent of the cases and instruments none. It was thus found that 22 35 per cent of the causes were failures of material. Miscellaneous reasons added 24.13 per cent; and only 6.78 per cent remained for the "undetermined and doubtful" classification. By this method it is possible, according to officials, to trace causes right down to magneto points, and hence back to faults of manufacture. Through a kindred system of vital statistics it can be ascertained which class of flying has the most accidents. For the first six months of 1928 only 34 accidents were in schedule flying, 69 in student instruction, 17 in experimental flying and 270 miscellaneous. Hearings are required where there have been accidents in order that the fullest possible information may be obtained.

Fuel Tanks and Supply Systems.—The problem of gasoline storage and method of supplying the carburetor is one that is determined by design of the airplane, the desired cruising range and amount of engine power supplied. While the object of designers should be to supply the fuel to the carburetor by as simple means as possible the fuel supply system of some airplanes is quite complex. The first point to consider is the location of the gasoline tank. This depends upon the amount of fuel needed and the space available in the fuselage. The fuel requirements may be estimated from the performance curves of the engines used.

A very simple and compact fuel supply system may be used on training planes. In this instance the fuel container is placed immediately back of the engine. The carburetor which is carried lower than the engine or tank is joined to the tank by a short piece of copper or flexible tubing. This is the simplest possible form of fuel supply system as gravity is employed to supply the fuel. The fuel tanks may be placed at the sides of the fuselage as in the Vought Corsair plane.

As the sizes of engines increase and the powerplant fuel consumption augments it is necessary to use more fuel, and to obtain a satisfactory flying radius without frequent landings for filling the fuel tank it is necessary to supply large containers, some of which may be carried below the engines.

When a very powerful powerplant is fitted, as on commercial planes of high capacity, it is necessary to carry large quantities of gasoline. In order to use a tank of sufficiently large capacity it may be necessary to carry it lower than the carburetor. When installed in this manner it is necessary to force fuel out of the tank by air pressure or to pump it out with a hand or wind driven suction pump to auxiliary tanks from which the feed may be by gravity because the gasoline tank is lower than the carburetor it supplies and the gasoline cannot flow from the main tank by gravity as in the simpler systems. The pump feed systems are generally used in airplanes at the present time.

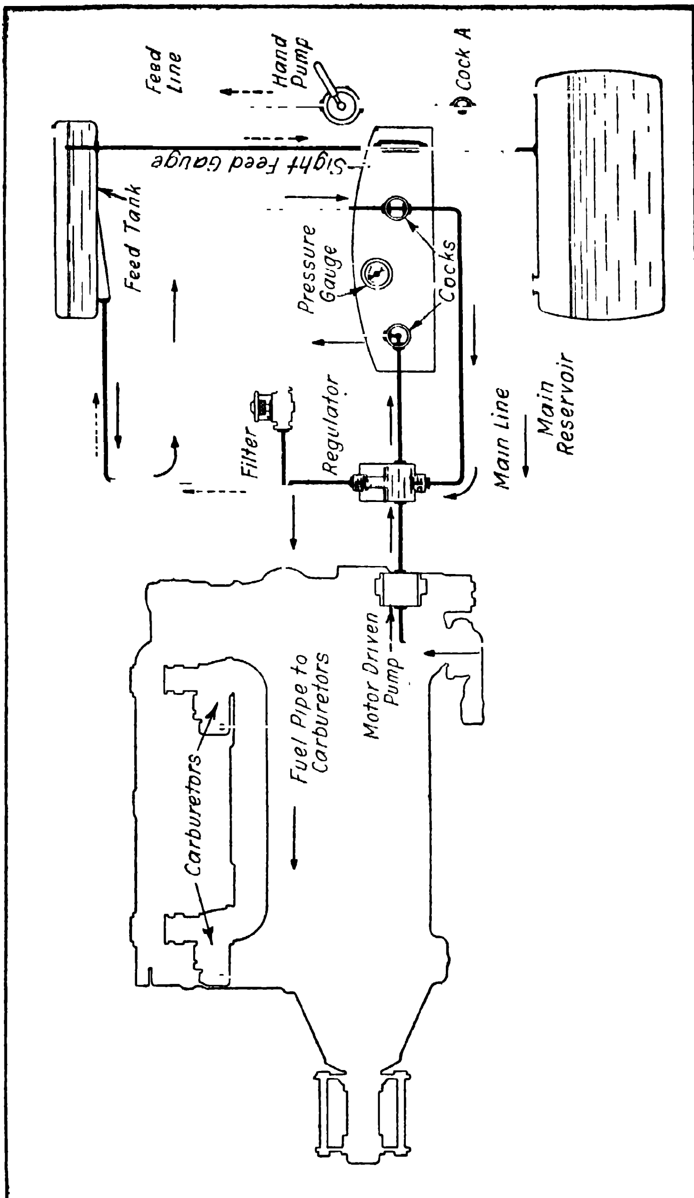


Fig. 754.—Typical Fuel Installation Recommended by Fiat Engineers for Use with Aviation Engines of Their Design.

The fuel system of the DH4 airplanes previously shown and described is typical of installations where fuel is displaced by air pressure from the main tank to an auxiliary tank in the center section. Two air pumps are used, one driven by the engine, the other by hand. In the type shown the main tank is carried back of the forward cockpit, a not entirely desirable location which was afterwards changed by putting it immediately back of the engine. A special fitting is used by which fuel may be supplied to the carburetors from the auxiliary tank or from the main tank. The hand pump is used to produce initial pressure on the main tank and fill the auxiliary tank by air displacement. Normally, the three-way pump valve is turned to the closed position. While in flight, the engine driven air pump supplies the air to the main fuel tank. Sometimes fuel is transferred from a main tank to auxiliary tanks by air propeller driven fuel pumps supplemented by hand pumps.

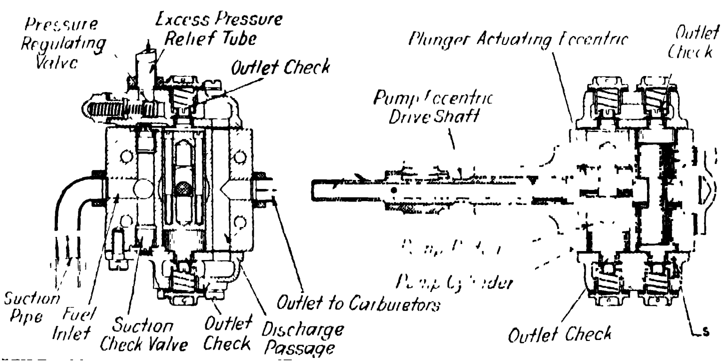


Fig. 755.—The Double Acting Plunger Type Fuel Pump Used in Fiat Fuel Supply System.

The fuel system recommended by the engineers of the Fiat company of Turin, Italy, is typical of modern practice. The main reservoir is carried below the carburetor level as shown at Fig. 754. A feed tank supplies the carburetors by gravity if desired and may be filled by the motor driven pump or by the hand pump. In event of failure of the motor driven pump, the hand pump of the "wobble type" will draw fuel from the main reservoir when the petcock A is opened. The feed tank, carried above the carburetor level has an overflow pipe leading to the main reservoir and can only be filled to a certain height. All fuel from either the main tank or gravity feed tank must pass through the filter before reaching the carburetors. The overflow passes through the sight feed gauge glass visible to the pilot and indicates when the gravity tank has been filled. A regulator device is incorporated in the main pump line as indicated, so a portion of fuel pumped in excess of the carburetor requirements passes into the gravity feed tank.

Fuel Pumps.—The double plunger pump used in the Fiat fuel supply system is shown at Fig. 755. This is simple in construction, the plungers being worked up and down in the cylinders by an eccentric shaft. The

plunger or piston is double acting and two plungers are used. The intake checks open on the suction stroke and the discharge checks on the discharge stroke. Owing to the number of pulsations in each revolution of the pump, fuel delivery should be very regular. The plunger pump used on the Maybach 300 horsepower engine to supply the carburetor is shown at Fig. 756 B. In this the plunger is reciprocated by a crank and Scotch yoke working in oil at all times, a special lead supplying the lubricant to the Scotch yoke chamber. Check valves regulate the fuel flow in and out of the cylinders

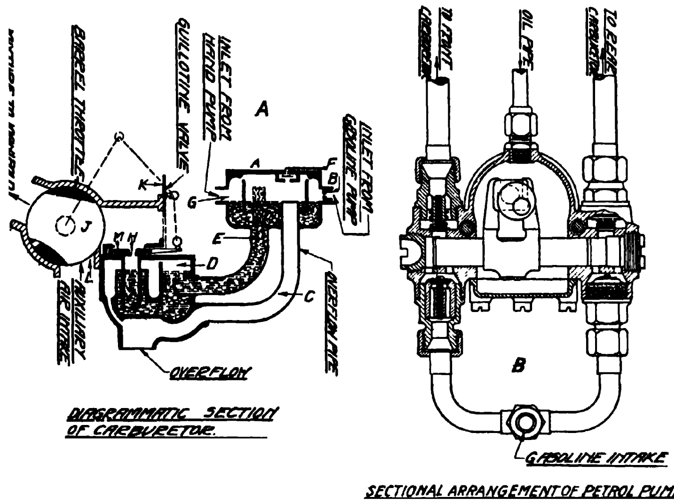


Fig. 756.—Sectional View of Maybach 300 Horsepower Engine Carburetor at A Uses an Overflow Chamber to Regulate Fuel Supply Instead of Conventional Float Bowl. The Sectional View at B Shows the Gasoline Pump.

in the usual manner. The carburetor is a type that does not use a float chamber, the fuel level being maintained by an overflow pipe which allows excess fuel to drain back to the supply tank. A diagram of the Maybach carburetor is shown at Fig. 756 A. Other forms of fuel supply pumps have been devised and several forms have been illustrated and described. These include metal bellows and diaphragm types mechanically actuated and diaphragm types electrically or magnetically actuated. Various forms of eccentric vane and gear pumps have also been used and representative examples will be found described and illustrated in various portions of this treatise.

AC Fuel Pump.—The AC fuel supply system is of the diaphragm type, an external view at Fig. 756 C showing simplicity of the appliance, the sectional view at Fig. 756 D showing the internal construction. This diaphragm is composed of several layers of especially treated flexible cloth material, which is impervious to gasoline and benzol. This cloth material (A) is held between two metal discs (B) and is pushed upward by a pump spring (C). In its upward position the diaphragm almost fills the pump

chamber (M) so that in its downward movements a very high vacuum is obtained, thus assuring high pumping capacity even at low speed. The repeated ¼ inch movement of the diaphragm is possible indefinitely without injury, due to the extreme flexibility of this material. Further, the extreme movement of the diaphragm occurs only when the carburetor is empty. When the carburetor is full, this movement is greatly diminished, being directly proportional to the amount of gasoline used by the engine. This means that in practically all normal driving conditions this diaphragm is pulsating in a movement of a few thousandths of an inch. This movement is controlled by linkage (F) because when the diaphragm is in the depressed position due to sufficient fuel in the carburetor the reciprocal movement of the lever (D) will merely cause a movement of the linkage (F) to the right as shown by the arrow.

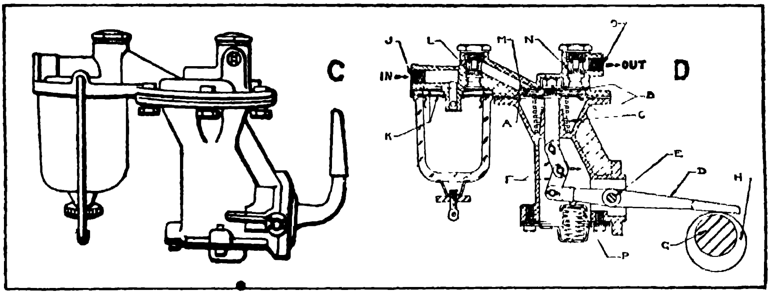


Fig. 756 C and D.--Illustrations Showing Construction of AC Diaphragm Pump Fuel Supply System for Automotive Engines.

Following is a description of a complete cycle in the movement of the fuel pump. (See Fig. 756 D.) By revolving shaft (G) the eccentric (H) will lift rocker arm (D) which is pivoted at (E) and which pulls linkage (F) together with diaphragm (A) held between metal discs (B) downward against spring pressure (C) thus creating a vacuum in pump chamber (M). Fuel from the rear tank will enter at (J) through strainer (K) and suction valve (L) into pump chamber (M). On the return stroke, spring pressure (C) pushes diaphragm (A) upward forcing fuel from chamber (M) through pressure valve (N) and opening (O) into the carburetor.

When the carburetor bowl is filled the float in the float chamber will shut off the inlet needle valve, thus creating a pressure in pump chamber (M). This pressure will force diaphragm (A) downward against the spring pressure (C) where it will remain in the downward position until the carburetor requires further fuel and the needle valve opens. Spring (P) is merely for the purpose of keeping operating lever (D) in constant contact with eccentric (H) to eliminate noise.

The company now has under development a large capacity fuel pump made of alloy steel and magnesium, which supplies sufficient fuel for a 500 horsepower engine and weighs complete less than two pounds.

Pressure System Has Fire Hazards.—The system of fuel supply involving pressure in the supply tanks to transfer the fuel is not favored because there is more danger of leakage and a consequently greater fire risk than

when there was only atmospheric pressure in a vented tank. Modern airplanes depend on engine driven fuel pumps to deliver fuel from the main tanks directly to the carburetors in some instances, in others, the mechanical fuel pumps deliver the gasoline to auxiliary tanks, from which fuel feed to carburetors is by gravity. When pressure is carried in the main tank, any slight leak around a rivet or in a soldered seam permits more fuel to escape than would be the case in a vented tank. During the War and for some time afterward, an air pressure system was used to supply fuel to the carburetors. A small engine-driven air pump maintained a pressure of two to four pounds per square inch on the tanks. Air pressure on the tanks constituted a very serious fire hazard in the event of a crash. The large tanks must be of very light construction and are therefore fragile. In the case of a burst tank, the air pressure caused gasoline and vapors to be sprayed around in the debris with almost a certainty of some of it finding

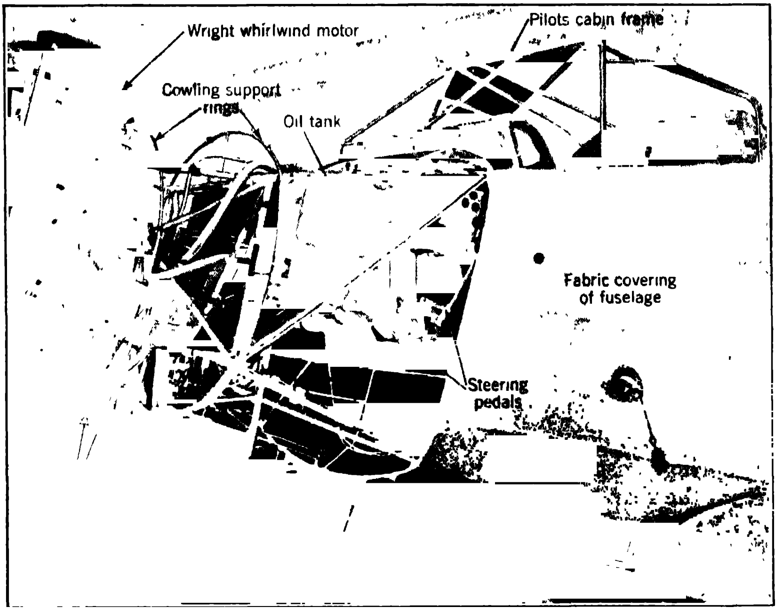


Fig. 757.—Nose Installation of "Whirlwind" Aviation Engine on Keystone Airplane Showing Oil Tank Installation Back of Motor.

its way to the hot exhaust stacks. At present, it is general practice to lead the fuel from the tank through a bypass around a hand pump, which can be operated by the pilot in case of necessity, to a very small engine-driven fuel pump. This pump delivers the gasoline directly to the carburetors at a pressure of from four to five pounds per square inch. A small spring-loaded valve is used to regulate the pressure and the overflow is returned to the tank. This overflow should not be returned to the suction side of the pump through a regurgitating valve because, at great altitude, the fuel becomes highly volatile and many bubbles are formed in the supply line,

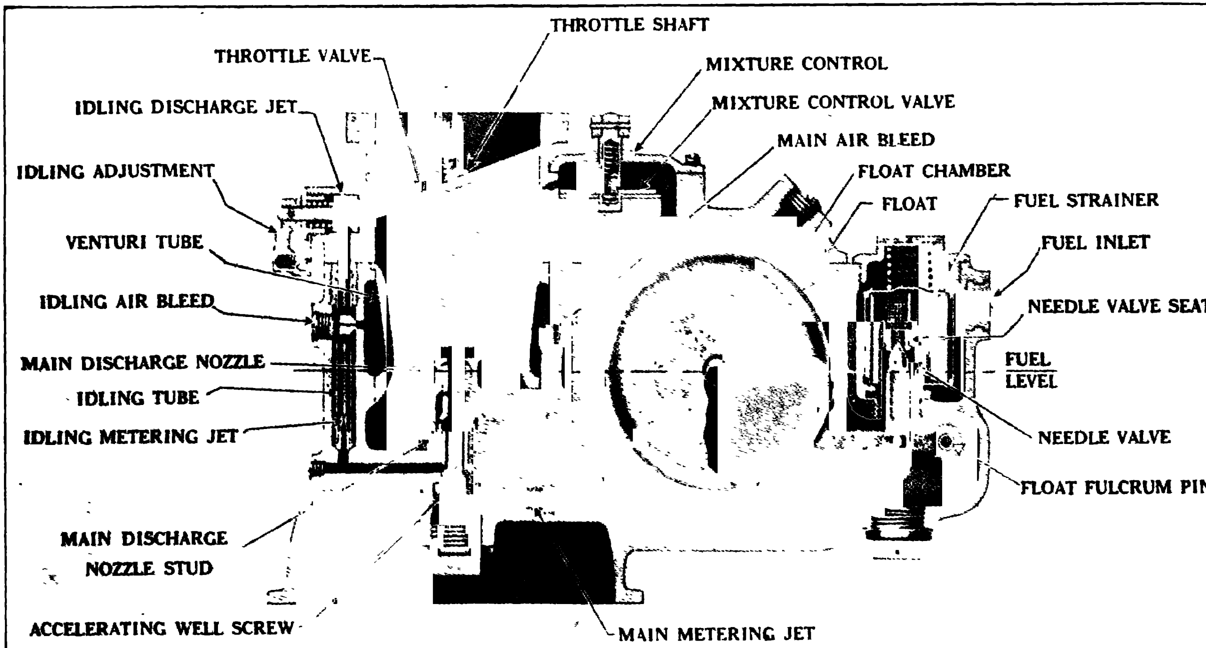


Fig. 757A.—Sectional View of a Stromberg Aviation Carburetor Showing the Float and Float Controlled Needle That Maintains a Constant Level in the Float Chamber as Indicated by the Dotted Line Marked "Fuel Level." The Float Rises When the Proper Level is Reached and Moves Needle Valve Against the Seat in the Fuel Inlet Chamber.

and if returned to the supply air bubbles would cause the pump to become airbound.

Oil and Fuel Tank Location.—The oil tank should be located immediately behind the engine and as close to it as possible. For all ordinary purposes a capacity of five gallons is ample for a 200 horsepower engine. The oil pipes from tank to engine should be short and direct, avoiding sharp bends which offer resistance to the free flow of oil. In case the airplane is to be used in extremely cold weather, that is, at temperatures below zero Fahrenheit, all oil lines as well as the oil tank should be lagged with asbestos sheet covered with doped fabric, thus preventing rapid loss of heat and improper engine lubrication through unduly thick oil. It is permissible to install the oil tank as high as twenty inches above the crankshaft center, since the oil will not drain into the engine when not in operation. The oil

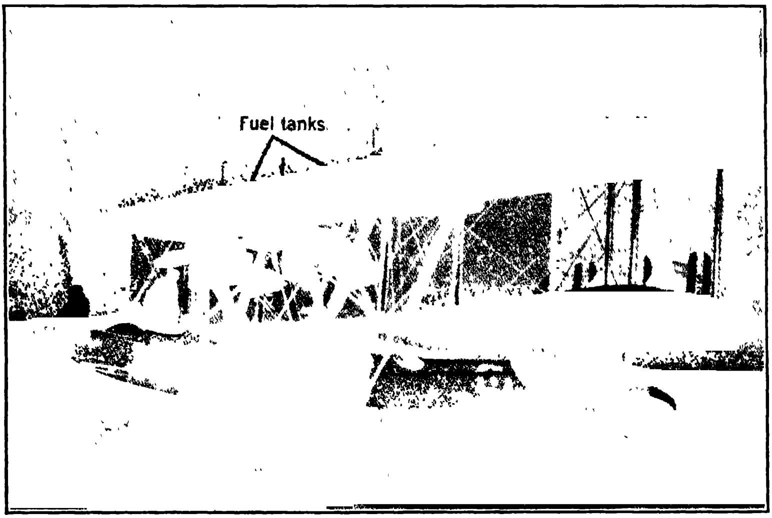


Fig. 758.—The Supermarine "Southampton" Twin Motor Flying Boat has Large Gravity Feed Fuel Tanks Mounted Below Upper Wing, One Tank for Each Motor. Main Fuel Tanks are Carried in Hull.

tank installation in the Gates-Day new Standard is shown at Fig. 748 and in the Keystone transport at Fig. 757. It is readily accessible in either of these locations and will be heated by the warm air passing through the radiator in Fig. 748 and from the air-cooled cylinders in Fig. 757.

The fuel tank can be installed in any convenient location, gravity feed to the carburetor being preferred but not required. As an accessory, an engine driven fuel pump may be obtained with most engines which feeds gasoline to the engine at adjustable pressure. With the airplane tail skid on the ground a head of at least twenty inches should be allowed so as to assure a steady flow of gasoline to the carburetor under all conditions if a gravity tank is used either as a main reservoir or a feed tank. The location in the "Supermarine" seaplane is shown at Fig. 758. The gravity tanks are mounted under the upper wing, one over each engine and these are placed high enough to insure gravity feed to the carburetors. There are

two objections to this tank location compared to location in the wings. They are hard to fill if used as main reservoirs and offer parasitic resistance. The advantage is their accessibility for repairs and the ease with which fuel connections can be inspected for leaks.

Duralumin Fuel Tanks.—When airplanes were first built, light gauge tinned copper was employed for fuel tanks, and brass and terneplate were also used. The reason for using these materials, despite their great weight, was that the tanks were of relatively small capacity and could be easily soldered at the joints and seams. As fuel tanks became larger, lighter materials were sought as the cuprous and ferrous metals or alloys were much too heavy. Duralumin has been successfully employed for fuel tanks by the Curtiss Aeroplane and Motor Company and other constructors; but through the discovery of a new plating process, it is possible to solder the material instead of welding it as was necessary in the past.

Inability to solder aluminum satisfactorily forced the use of a welded construction on these tanks. This type of construction was extremely difficult and expensive, and the appearance of the finished product was not highly satisfactory. In addition, service difficulties developed; a sediment formed which interfered with the gasoline flow; leaks were frequent, and repairs in the field were difficult—in fact, almost impossible. In spite of these drawbacks, aluminum tanks have come to be extensively used in aircraft, solely because of their great weight advantage. It is interesting to note that probably the first aluminum tanks to be used in this country were those built by the Curtiss Company and installed in the NC boats, one of which, in 1919, made the first flight across the Atlantic, via the Azores.

Realizing that the ideal type of tank would be one which would combine the lightness of the aluminum type with the low cost and excellent service features of the brass tank, the Curtiss Company set about to develop such a tank, and, after a great deal of research and experimentation, has produced a duralumin tank. The special nickel-plating process was developed by William J. Travers, of Buffalo, N. Y., and Curtiss is the sole aeronautical licensee. Plated duralumin tanks, therefore, can be made by the same methods as brass tanks, which means ease and low cost of manufacture. They stand up well in service, develop no deposit to interfere with fuel flow, and, if damaged, can be repaired easily with an ordinary soldering iron. Combined with these advantages is the extremely low weight of the duralumin.

The importance of this weight saving can easily be seen when one realizes that on the Curtiss Hawk pursuit plane, for example, a saving of about 45 pounds has been realized by making the gasoline and oil tanks of duralumin instead of brass, and this saving would, of course, be increased in larger machines. Since the weight carried by the Hawk is 6½ pounds per horsepower, the saving of 45 pounds means that seven horsepower has been released to do useful work in propelling the airplane. Plated duralumin tanks have undergone all kinds of service tests for the past two years, and have shown up so satisfactorily that all tanks now being made by the Curtiss Company, including those for the U. S. Army and Navy Hawks and the Army Falcons, are of plated duralumin. These tanks are also being manufactured by the Curtiss Company for the trade.

Various forms of crash-proof and bullet-proof tanks in which double walls with some special sealing compound between them, intended to close any holes in the tank automatically or tanks provided with special coverings to do the same work have been experimented with for military airplanes but most commercial machines use single walled tanks. Tanks of very large bombing planes are sometimes provided with quick opening dump valves so the plane can be quickly lightened by discharging main tank contents in event of having to make a forced landing due to motor failure while heavily loaded. It is not always practical to land a very heavy plane with a dead stick without danger of a crash due to landing gear failure if the ground surface is not extremely favorable to a smooth landing. In multi-motored airplanes, in event of one engine stopping, it may be necessary to lighten the plane by releasing some of the fuel in order to maintain flight under certain conditions. Smaller commercial planes are not provided with such valves. In some types of military airplanes, the fuel tanks are so installed that the entire main tank may be dropped from the fuselage in an emergency. When land planes are flown over water and a forced landing impends, a dump valve is valuable because considerable flotation properties may be present in an empty large capacity fuel tank that will help keep the airplane afloat, so the tank must be provided with means for quickly emptying it.

Installing Typical Water Cooled Aviation Engine—The Curtiss D 12

Unpacking Curtiss D12 Engine.—Curtiss Model D12 engines are shipped from the factory enclosed completely in substantial boxes. Each engine is bolted to two beds or sills mounted on the bottom of the box. To unpack the engine, remove the wood screws which hold the eight sheet steel straps to the sides of the box, or on some boxes the six bolts holding the three-eighths inch steel straps together. The cover of the box and the four sides may be lifted vertically from the floor of the box. (See Fig. 759.) The tool kit, accessories and other miscellaneous equipment are boxed in a separate compartment of the packing case.

In hoisting the engine from the sills two flexible quarter-inch diameter wire cables about eight feet long should be used. These cables should be bound with tape or rawhide to protect the engine enamel. The cables should be placed around each cylinder block under the exhaust ports and between the cylinder head and camshaft driveshaft housings. Be careful to avoid having the cables catch on the studs.

Do not use "dope" solvent, alcohol, mixtures or benzol for cleaning the engine as they are paint removers. Avoid wetting the magnetos. Light grade Corol compound manufactured by the Simonize Co., Chicago, Ill., is used for rust prevention on the exterior of the engine. It need not be removed when the engine is put into service.

Installation of Curtiss D12 Engines.—The engine should be well braced and the structure should show no undesirable vibration when the engine is in operation. Three-eighths inch engine bed bolts should be used. If wooden bearers are used they should be metal faced under the engine legs or supports to prevent chafing. All legs should rest evenly on the beds

before tightening the "hold down" bolts. Washers approximately one and one-half inches in diameter by one-eighth inch thick should be used on the lower side of the bed to prevent the head of the bolt or the nut from cutting into the wood. Nuts should be cottered carefully. Always use a $\frac{1}{32}$ inch steel plain washer between the aluminum leg and the nut. A typical installation is shown at Fig. 760. Wiring:—Wiring to the magnetos and hand starter should check with Diagram C-4,652 (Fig. 761) for Splitdorf SS-12 magnetos.

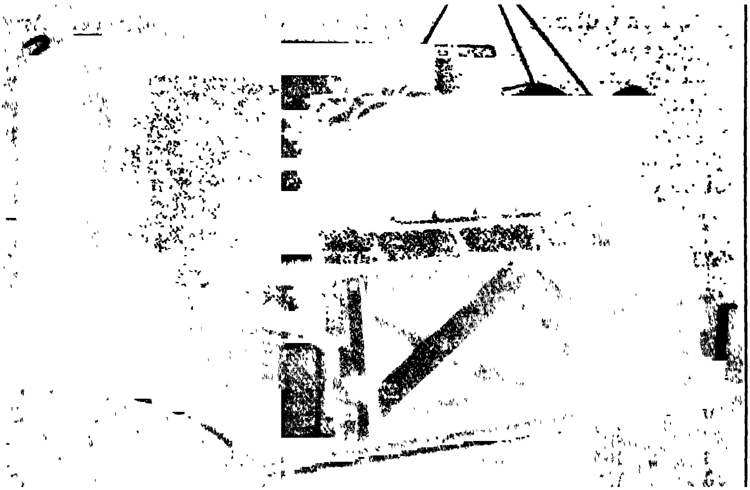


Fig. 759.—Shipping Crate Used for Curtiss D12 Aviation Engine. Illustration Also Shows Correct Method of Slinging When Transporting Motor.

Carburetor Controls.—Throttle and mixture controls should open and close fully and easily, and there should be sufficient friction on the levers in the cockpit to prevent any changing of the position of the levers in flight except by the pilot. A lock should be provided for the throttle to hold the lever in the closed position, so that the operator can start the engine alone without fear of the airplane running away when wheel "chocks" are not available.

Fuel System.—It is recommended that all fuel connections between different units in the installation which might vibrate relative to each other be made with a short length of gasoline resisting rubber hose, using a connection designed to prevent actual contact of the hose with the fuel in the pipes as shown at Fig. 753. This method of connection can be used with 100 per cent benzol without deterioration from the use of this fuel. A flow indicator should be used in the overflow line from the reserve tank, if possible, to indicate to the pilot whether the gasoline pump is or is not working. Drains from the carburetor air scoop should be led outside of the airplane fuselage. The gasoline pump should maintain from three to five pounds per square inch gauge pressure. The low compression engine (5.3 to 1 compression ratio) should use domestic aviation gasoline or its equivalent.

Use a mixture of 25 per cent benzol and 75 per cent domestic aviation gasoline for the high compression engine.

Cooling System.—All water connections should be made with suitable hose clamps and should not be bound with tape under the hose, over the hose, or over the hose clamp. Inspect all joints for leakage after the system has been filled with water. Great care must be taken to vent the cooling system so that air or steam pockets can not form. The header tank should be located as high as possible above the engine and the cooling water should circulate through it. The discharge into this tank should be located so that the water will not surge out of the overflow or vent pipe. Any point in the engine which might be higher than the header when in flight should be vented by means of a small pipe to this tank, and the outlet of these vents should always be the highest point in the system.

No anti-freeze compounds containing salts or alkali should be used in the engine, as they corrode the aluminum water jackets and water pump. Alcohol or glycerine are recommended, as shown in the following tabulation:

WATER AND DENATURED ALCOHOL ANTI-FREEZING MIXTURE

% Volume of Alcohol	*Beaumé Reading*	*Specific Gravity of Solution of 60° F.*	*Freezing Point of Solution*
10	12°	.988	27° above zero F. or 3° below zero C.
20	13°	.978	19° above zero F. or 7° below zero C.
30	15°	.968	10° above zero F. or 12° below zero C.
40	16°	.957	2° above zero F. or 19° below zero C.
50	18°	.943	18° below zero F. or 28° below zero C.

GLYCERINE AND WATER ANTI-FREEZING MIXTURE

% Volume of Glycerine	*Beaumé Reading*	*Specific Gravity of Solution of 60° F.*	*Freezing Point of Solution*
10	4°	1.029	29° above zero F or 2° below zero C.
20	8°	1.057	21° above zero F. or 6° below zero C.
30	11°	1 085	12° above zero F. or 11° below zero C.
40	15°	1 112	0° above zero F. or 18° below zero C.
50	18°	1.140	15° below zero F. or 26° below zero C.

Ice crystals start to form at the above temperatures, the solutions freezing solid at temperatures about 10° lower.

Alcohol-water anti-freezing mixtures have probably been most commonly used to date, owing to the fact that alcohol is easily obtainable at reasonable cost. The grade used may be either denatured or wood alcohol. Alcohol solutions do not have any greater tendency to corrode the metallic parts of the system than water alone. However, wood alcohol will often contain free acetic acid. It is advisable as a result not to use wood alcohol unless it is definitely known to be acid free. Where using alcohol it is important to remember that this product will evaporate far more rapidly than water. Hence a certain amount must be added as make-up from time to

time to keep the concentration of the mixture as desired. For this reason it is well to test the specific gravity of the alcohol mixture regularly with a hydrometer calibrated for temperature correction, and check the reading with the above table.

Alcohol, however, lowers the boiling point of water to quite an extent if used in large amounts. Consequently, it may frequently happen that on a comparatively warm day when the engine is "idled" the solution will boil readily and abnormal evaporation will take place, thus raising the freezing point of the remaining mixture. To overcome this tendency it is

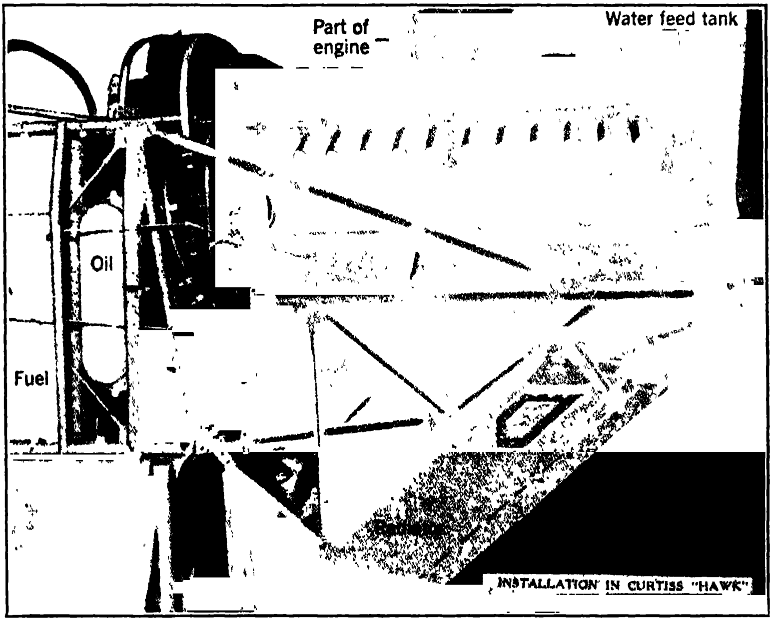


Fig. 760.—Installation of Curtiss D12 Engine in Curtiss "Hawk" Airplane. Note also Radiator Suspension Below Crankcase. The Motor Mount is of Steel Tubing and is a Braced Cantilever Type Typical of Approved Modern Practice.

often preferred to use a mixture of equal parts of alcohol and glycerine, etc., as the anti-freeze component in the cooling water. A special cooling liquid known as Prestone has been used successfully and is not so apt to boil away as alcohol.

Propeller.—In mounting the propeller on the tapered end of the crankshaft, extreme care should be exercised. Clean the shaft and the hole in the hub. Lubricate the crankshaft, the tapered hole in the hub and the threads both in the hub and the nut with cylinder oil. Do not use graphite in any form. Note that with the hub pushed on the taper by hand that there is .002 to .004 inch clearance between the hub and shaft at the small end. This is done to prevent chattering and seizing at the large end of the taper. The hub should not be lapped on the crankshaft taper on the Curtiss D12, though this procedure is advised by some other engine builders.

Start the attaching nut about one thread on the crankshaft before starting the outside threads on the nut into the hub. After the nut has been tightened securely, the fine threads on the outside of the nut should be flush with the end of the hub or there should be about two threads projecting. Never have these fine threads screwed below the end of the hub, or have more than two threads showing.

When mounting the "R" type propeller with its steel sleeve the locking pin must enter the hole. Tighten the nut as tight as possible, using a four foot bar ⅞ inch in diameter. The tighter the hub is put on the shaft the easier it will come off later. Clean and oil all threads well before assembly. Put in the locking pin and wire it with iron wire around the end of the hub in the groove provided. When mounting the propeller on the hub, the propeller should be carefully tracked within one-eighth of an inch. All nuts are cottered.

Lubricating System.—In connecting the oil tank to the engine never locate the tank so that the bottom comes more than six inches below the oil pump inlet which is marked "Oil In." Also do not locate the oil tank above the engine. The suction line from the tank should be at least three-quarters of an inch inside diameter. Figure to have at least two gallons of oil left in the tank after the gasoline supply has been exhausted. Also have at least two hundred cubic inches of expansion space (equivalent to slightly less than a gallon) in the tank after it has been filled to its full capacity The engine often has a quantity of oil left in the oil pan after running and this will be pumped into the supply tank immediately upon starting the engine. Therefore, do not fill the supply tank so full that the expansion space is filled after the engine starts. If the tank is filled too full it will be subject to pressure because of oil being forced up the vent pipe. The oil is heavy and offers considerable resistance to flow. Locate the filler openings so that the expansion space cannot be filled with oil. The vent should be located in such a position that the oil in the tank will never close it in normal flight. This vent should be connected with one-half inch tubing to the vent connection on the engine. The vent connection is located on the cap on upper end of the vertical driveshaft, or in the propeller end of the crankcase.

The suction line from the tank to the pressure pump should be tapped into the lowest point in the tank when the airplane is level. The discharge into the tank should be directed or baffled so that no oil can continually pass out the vent line since this vent line must be free to take care of air pumped into this tank by the scavenging pumps. The best method is to direct the return oil against the top of the tank so that the air and oil can separate. The oil pressure gauge should be connected to the engine with a one-quarter inch annealed copper tube, precaution being made to guard against harmful effects of vibration. The oil thermometer should be connected into the fitting provided for it on the right hand side of the engine.

Cooling the lubricating oil by air directly is not satisfactory. Cooling the oil with water in the engine cooling system has proven very satisfactory, and the success or failure of an installation often depends greatly upon the proper cooling of the oil. The use of a cartridge tube oil radiator enclosed in a metal water-tight container is recommended. The cooling water from

the radiator should pass through this cooler and the oil returning to the tank should also pass through the cooler. All water and oil outlets from the cooler should be at the topmost points to prevent air trapping. Detailed information on the proper design of an oil cooler for any D12 engine installation will be furnished on request by the Curtiss Aeroplane and Motor Company, Inc.

Generator.—The upper end of the vertical driveshaft in the gearcase is splined for an Air Corps type E-3 generator. The nut on this vertical shaft is pinned to the shaft with a taper pin. This pin should never be removed while the engine is in service, since the nut will loosen if the pin is not in place. A special locking device for this nut can be procured for use with the generator.

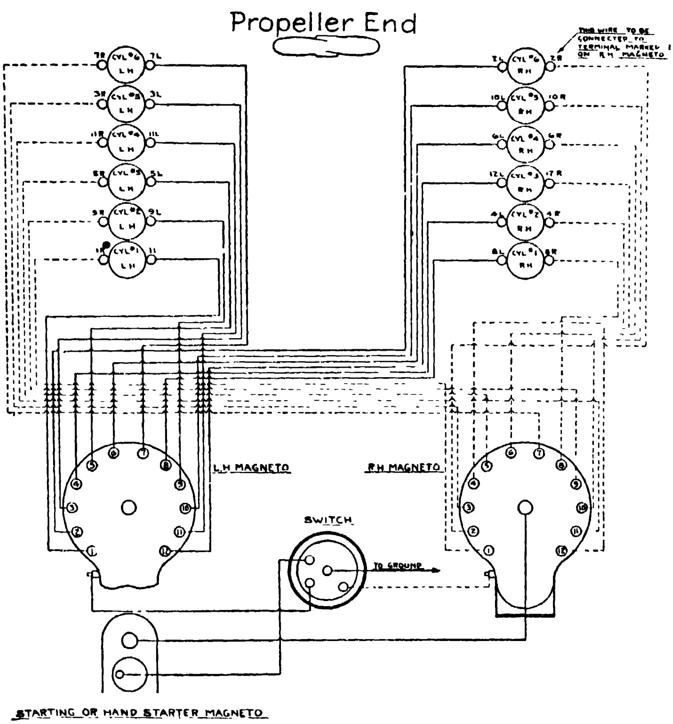


Fig. 761.—Wiring Diagram for Splitdorf Magnetos Used on Some Curtiss D12 Engines. Note Connections of "Booster" or Hand Starter Magneto.

Operation of the Engine—Inspection.—See that the cooling system is filled with water and that there are no leaks. The oil tank should contain the proper capacity of oil as recommended. The gasoline tank should be filled with domestic aviation gasoline or the proper fuel as stated in the specifications of the engine. If the engine has been in storage or idle for a considerable period, about a tablespoonful of cylinder oil should be injected into each cylinder and the engine turned over several times before

starting, to lubricate the cylinder walls. Turn the shaft over at least twenty times. Have the throttle wide open and have no fuel in the carburetor.

Controls.—Set the spark lever about two-thirds from the retard position, for all except hand starting. For hand starting have the spark full retard. The mixture control should be full rich, and the throttle closed tightly.

Starting.—With the controls set as above, crank the engine at least two full revolutions, or in cold weather until the engine turns freely, open the throttle about one-tenth of its full travel, pull the engine over one cylinder, put ignition switch in the "both" position and operate the starting or hand magneto instantly. Any delay in operating the hand cranking magneto will allow compression to leak and make the starting harder. When the engine starts advance the spark immediately, and when using the hand starter with geared starting magneto attached, continue turning the crank handle until the engine runs steadily. With inertia starters be sure everyone and everything is clear of the propeller, before the ignition switch is put in the "both" position. Trip the starter mechanism. If the starter slows down too much before the engine starts put the switch in the "OFF" position.

Gas mixture can only be drawn into the cylinders for starting when the throttle is closed as stated above. A feeble, soft explosion indicates a rich mixture which should be pumped out of the engine by turning the propeller backwards with the switch "OFF" and the throttle wide open.

Over priming or too much cranking is the cause of poor starting in most cases. Too much cranking when the engine is hot will invariably fill the cylinders with a mixture too rich for starting. One turn of the propeller when the engine is hot is sufficient for starting with the booster. If an inertia or hand starter is used open the throttle slightly before engaging the starter. Be sure the ignition is on. If the engine does not start the first time, clean out the rich mixture by rotating the propeller backwards before attempting another start. Do not attempt to start with the ignition retarded fully. Start with the ignition partly retarded or advanced fully. Continued priming or cranking results in poor compression owing to the cylinder walls having been washed by gasoline. Poor compression from this cause can be cured by the injection of hot oil in a small quantity in each cylinder through the sparkplug hole. Too much priming is liable to cause scored pistons or cylinders.

Observations at Start.—The oil pressure should be noted immediately to determine whether or not the oil pump is functioning. If there is no oil pressure after fifteen seconds, stop the engine and find out why there is none. Remedy the trouble.

The outlet water temperature should not exceed 180 degrees Fahrenheit, with 160 degrees Fahrenheit, desired operating temperature. The operating inlet oil temperature should never exceed 150 degrees Fahrenheit, and 140 degrees Fahrenheit is desired. At 1,800 r.p.m. the oil pressure should be about 100 pounds per square inch, and the gasoline pressure should be from two to four pounds per square inch gauge. After the engine is warmed up and all parts are functioning properly the throttle should be opened wide for about one minute before taxiing to take-off.

Oil Pressure Regulation.—Never change the oil pressure until it has been checked carefully with the engine warmed up thoroughly. The pressure can be altered by varying the thickness of the washers on the relief valve. The oil pressure is set correctly when the engine leaves the factory and should require no readjusting. An improperly designed oiling system in an airplane, or a broken line will cause variation in the pressure and these facts must be considered carefully before regulating the pressure. The pressure gauge should be checked for accuracy. A dirty oil screen in the engine will cause a marked drop in the oil pressure, usually after about thirty hours of engine operation. Therefore, keep all suction lines clean, short, large diameter and the oil screen clean.

CARBURETOR SETTING FOR STROMBERG CARBURETORS
FOR LOW AND HIGH COMPRESSION D12 ENGINES

	NA-Y5D	NA-Y5F
Venturi	1¼"	1¼"
Main metering jet	No 46	No. 44½
Main air bleed	No. 49	No 49
Upper well bore	7/32"	7/32"
Lower well bore, with pulsation control nozzle	No 29	No. 29
Upper row well holes	4—No. 50	4—No. 50
Lower row well holes	8—No 44	8—No. 44
Idle metering jet	No. 61	No. 61
Idle air bleed	No. 47	No 47
Idle discharge jet	No. 48	
Mixture control suction jet	No. 40	No. 48
Discharge nozzle holes	6—No. 26	No. 40
Mixture control valve closes on	No 60 drill	
Float level—below parting surface	⅛"	⅛"
Float needle seat		No. 9

Magneto Timing:

Low Compression.—Intake Magneto Fires Full Advance B.T.C. 32°
Exhaust Magneto Fires Full Advance B.T.C. 36°
High Compression.—Intake Magneto Fires Full Advance B.T.C. 33°
Exhaust Magneto Fires Full Advance B.T.C. 38°

Care of D12 Engine.—A general surface inspection should be made after each flight and the engine prepared for immediate flight. It is not necessary to remove sparkplugs unless the action in operation indicates that there is a defective plug.

During cold weather the water should immediately be drained from the engine if it is to be idle long enough to freeze unless the proper anti-freeze solutions are used.

Check the magneto breaker points, valve clearances, and all outside nuts, bolts and connections after each 25 hours of flight service. Change the oil in the lubricating system.

An overhaul is recommended after 200 hours of flight service. (See special Chapter 37 on Curtiss D12 Engines.)

After an overhaul run the engine "in" slowly, starting at 600 r.p.m. Use a mixture of 80 per cent gasoline and 20 per cent benzol for fuel for low compression and 75 per cent gasoline and 25 per cent benzol for high

compression engines. Always use new oil of a grade recommended for use in the engine.

Let the engine idle until the oil and water are warm and then increase the speed by steps of 100 r.p.m. every fifteen minutes. For a test propeller that allows the engine to run 2,300 r.p.m, with the throttle wide open this procedure should be followed up to and including 1,700 r.p.m. Then open the throttle to a point where the propeller is turning at 95 per cent of its rated speed. Run the engine at this speed for at least one-half an hour and preferably one hour before fully opening the throttle. Run at full throttle for only a few minutes and then throttle the engine down slowly and let it

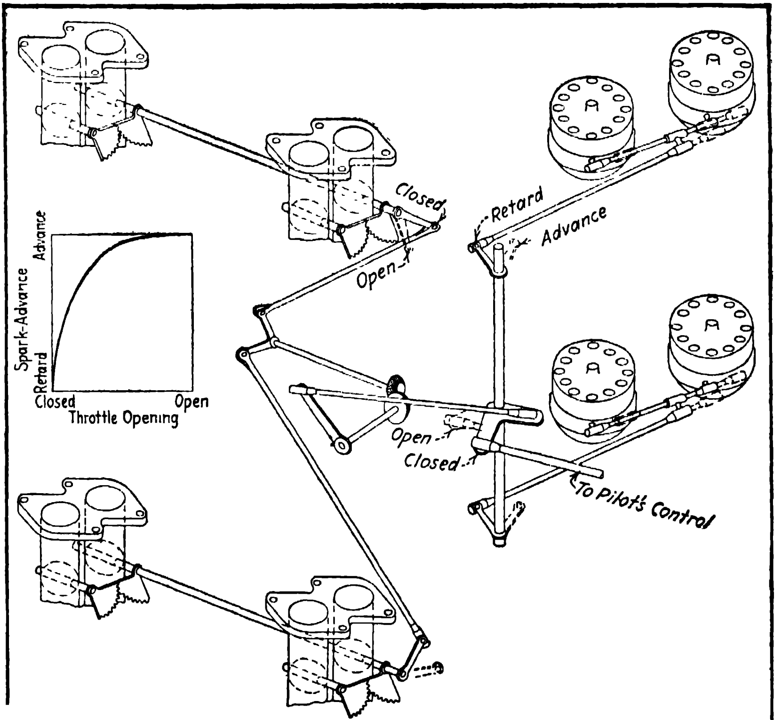


Fig. 762.—Spark and Throttle Hook Up of Packard X Engine Provides for Simultaneous Control of Ignition and Carburetion.

idle for about ten minutes. Shut off the fuel supply and let the engine stop of its own accord. This approximates the "running in" procedure carried out at the factory. Be alert at all times for indications of trouble. Shut the engine down quickly at any indication of trouble and investigate.

For propellers that do not allow the engine to run at its rated speed start running at 600 r.p.m., and increase by increments of 100 r.p.m. every fifteen minutes until the propeller is turning at about 75 per cent of what it is supposed to turn with the throttle wide open. Then increase the throttle opening until the speed is 95 per cent of the speed the propeller is supposed to

run. Run at this position one-half to one hour before fully opening the throttle. After a few minutes at full throttle slow the engine down carefully and let it idle for a time, then shut off the fuel supply and allow the engine to stop of its own accord. Shut the ignition switch "OFF" after the engine stops.

Cleaning of Oil Screens.—The oil screen under the plate marked "OIL IN" should be removed every 25 hours of engine operation and thoroughly cleaned. The oil screens for the scavenging system should be cleaned and inspected every time the oil pan or oil pump assemblies are removed.

Storage.—If the engine is to be stored, or is to be shipped a long distance all external steel parts should be sprayed with Corol compound light grade or similar anti-rust compound. The oil pan should be removed if possible and all internal parts coated (preferably by spraying) with the compound. Re-assemble the oil pan and lock up all screws and nuts that

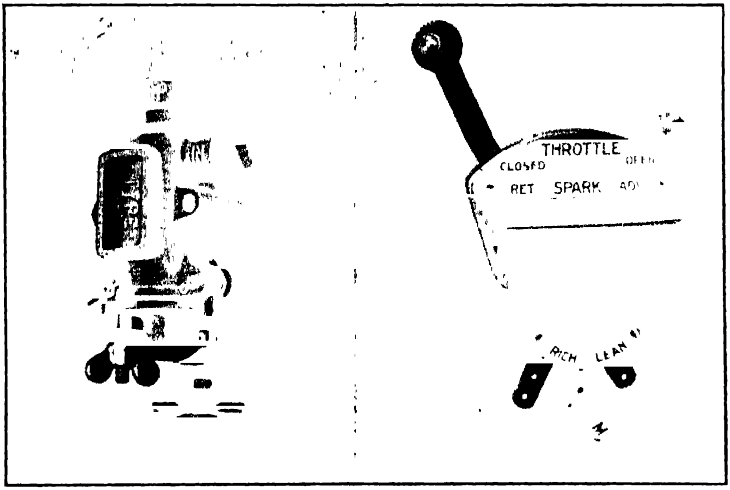


Fig. 763.—Consolidated Instrument Company of America Fuel Filter at Left and Engine Control Lever Assembly at Right of Illustration.

should be. Remove the exhaust sparkplugs and spray compound in the cylinders Replace the sparkplugs. Be sure the propeller shaft (and its threads) has a heavy coating of compound or grease. If anti-rust compound is not available put about a teaspoonful of cylinder oil in each cylinder and turn the crankshaft 25 or 30 times to spread the oil over the cylinder walls.

Details of Engine Control.—The diagram of the spark and throttle hook-up shown in Fig. 762 represents a special Packard development intended to simplify the duties of a racing pilot, but the result has been so satisfactory that it is worthy of more general adoption in commercial airplanes as far as the interconnection of spark and throttle is concerned.

Regarding the function and uses of each of the three engine-controls commonly used with an aircraft engine, the spark-advance control normally is used for starting and for especially slow idling. At all other times the

spark control is left in the fully advanced position. The throttle control is used to vary the speed of the engine, and the mixture control normally is required only for leaning the mixture at altitude.

In a racing airplane which flies low there is no need for mixture control, and this leaves only the spark and the throttle controls to be dealt with. One advantage of battery ignition, with which the Packard X-type engine is equipped, is that a considerable range of spark advance and spark retardation can be secured, which is not true of magneto ignition. This range proves to be of particular value in idling the engine down to very low speed while still maintaining sufficient velocity through the carburetors to eliminate the possibility of choking the engine. This very slow idling is highly desirable when landing. The leverage arrangement is simple for moving the controls simultaneously in accordance with some such curve as is shown

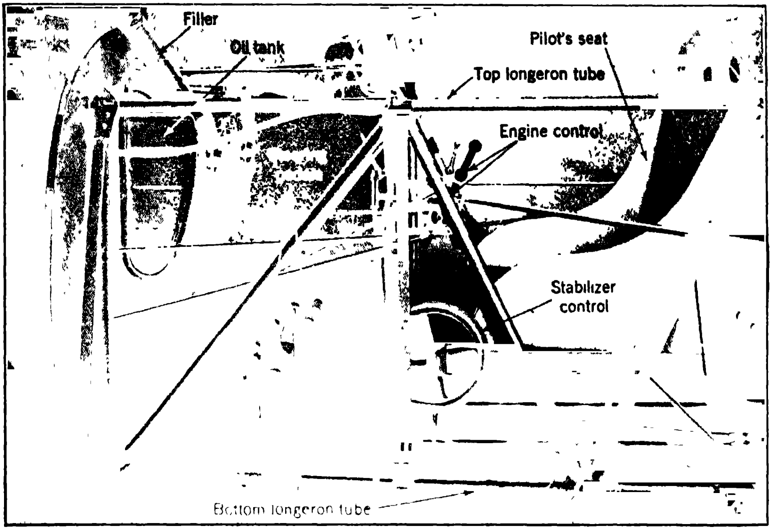


Fig. 764.—Midship Section of Fuselage of Vought "Corsair" Airplane Showing Oil Tank Installation and Location of Engine Control Levers Relative to Pilot's Seat.

in the left middle portion of Fig. 762. It will be observed that, for starting, the throttles are closed and the spark fully retarded. Once the engine is started, it is desirable to advance the spark somewhat before opening the throttles to prevent the engine from "spitting back." Further acceleration of the engine up to cruising speeds is obtained by operating both the spark and the throttle controls simultaneously so that, at cruising speed, the spark is fully advanced although the throttle is only partly open. From cruising speed to top speed, the engine speed is controlled solely by the carburetor throttles.

The method by which this desirable control is effected is clearly shown in the diagram. No cams or springs are employed in the hook-up, the result being achieved merely by locating the various levers on their shafts in the

best location to suit the requirements. For example, the throttle connecting rod practically passes over center when first opened, and a similar toggle action is secured with the spark-control rod as soon as the spark is fully advanced. This results in obtaining automatically the best response of the engine as the need arises, with only one engine-control lever for the pilot to manipulate.

In commercial airplanes, and in the usual military types, separate control of the spark, throttle and mixture is necessary so the assembly shown at the right of Fig. 763 built by the Consolidated Instrument Company of America, Inc., is a standard installation on most airplanes. The illustration at Fig. 764 shows the mid-section of a Vought Corsair airplane and shows the location of the engine control assembly very clearly. Connections are made from spark and throttle and mixture control levers to the elements on the engine auxiliaries by push and pull rods of light tubing. The instrument board carried above the fuselage and immediately in front of the pilot's seat serves as a mounting for the various engine recording instruments. The hand wheel conveniently placed near the pilot's seat is used to vary the angle of incidence of the tail stabilizer. The oil tank is placed back of the bulkhead between the pilot's compartment and the motor. Various details of the airplane control, such as the stick and the rudder operating pedals as well as the steel fuselage construction can also be studied from this illustration. While every effort is made to have important engine controls as direct and positive as possible, sometimes the engine location is such that flexible wire is necessary. Where control direction must be changed around a corner the use of Ahrens controls is much more practical than using bell cranks because there is no lost motion in this type of fitting.

QUESTIONS FOR REVIEW

1. What is the value of inverted engines?
2. What is the usual form of water-cooled engine mounting?
3. What materials are used for engine mounts?
4. Why is a cantilever tubing mounting used?
5. What is the effect of radiator placing on resistance?
6. Outline some precautions in installing water-cooling systems.
7. Name common methods of radiator temperature control.
8. Give principal rules for engine mounting.
9. How big must a lubricating oil tank be?
10. Name usual fuel tank locations.

CHAPTER XLI

AIR-COOLED ENGINE INSTALLATION

Installing Air-Cooled Engines—Nose Motor Installation Easy—Outboard or Wing Motor Installation—Requirements of Engine Mount—Disposition of Exhaust Important—Cowling for Weather Extremes a Problem—Difficulties Presented by Exhaust Manifolds—Carburetor Stove for Zero Temperature—Installing Fairchild-Caminez Engines—Mounting the Engine—Lubrication System—Magneto Wiring—Spark Control Lever—Tachometer Drive Connection—Engine Starter—Propeller—Installation of Wright Whirlwind Engine in the Airplane—Unpacking and Cleaning—Lubrication System—Cowling—Fuel System—Magneto Wiring—Carburetors for Whirlwind—Starter—Mounting the Propeller—Instructions for Starting and Normal Operation, Wright Whirlwind—Starting—Ground Test—Flight—Landing—Fuels—Oil—Unpacking and Cleaning Wright Cyclone Engines—Fuel and Oil Lines—Cyclone Lubrication System—Fuel System of Cyclone Engine—Carburetor Air Heater—Magneto Wiring—Miscellaneous Connections.

Installing Air-Cooled Engines.– The installation and cowling of the air-cooled radial engine is an important feature and has a direct bearing on the satisfactory operation of the powerplant considered as a whole. No general rules covering all conditions can be laid down, although experience has proven certain general principles as satisfactory. The metal fuselage structure is now almost universally used in modern military and commercial aircraft. In the same way, the metallic engine mount is considered the best practice and gives an almost ideal structure for the radial air-cooled engine, since ample accessibility is obtained for accessory adjustments behind the engine, and suitable bearing supports are available for the oil tank, starter-handle, gasoline strainer and other accessories.

Either a flanged plate, or a circular bent tube engine mounting ring is good practice. In case the latter is used, the engine bolts can be held by suitable clips welded to the ring, or by running them directly through the ring tubing, after properly supporting the tube section by a short welded-in tube whose inner diameter is slightly larger than the engine bolt. This short tube prevents crushing the ring section. The engine mount of the Vought Corsair airplane shown at Fig. 765 is typical of good practice. It is made to support the Pratt & Whitney Wasp engine and its installation to the front of the fuselage shown at Fig. 764 is clearly outlined in Fig 766.

Either tubing or formed sheet bracing to the mounting ring is permissible. In either case the mounting ring braces from the longerons should be so placed as to form a series of triangles, one in each plane of the fuselage. If the tubing mount is used, the brace tubes in each of the four fuselage planes should meet at a point on the mounting ring. In case interference with the carburetor is encountered in the bottom fuselage plane, it is permissible to spread the brace tubes in that plane a distance of several inches. Cowling is desirable on all engines except those in use in tropical climates. Not only does it improve the airplane performance by better streamline, but it protects the engine crankcase from over-cooling, which tends to congeal the oil. It is impossible to set forth any rigid rules for

cowling an engine since the individual requirements of various airplane designs are different. In general, it is desirable to allow for a blast of air on the cylinder barrels as well as on the cylinder head, but since there are several different ways of making such an installation, engine builders strongly advise designers to draw up their own ideas of cowling and cowl lines and submit them to their Plane Engineering Department for comments and suggestions.

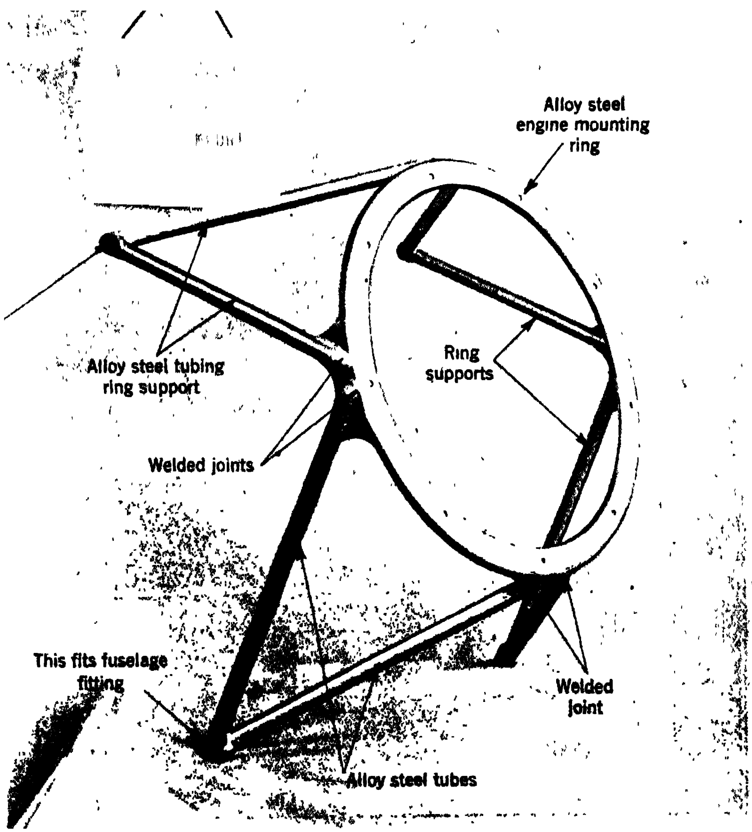


Fig. 765.—This Simple and Light Engine Mount is Strong Enough to Support the "Wasp" Engine Used on Vought "Corsair" Airplanes. It is Made of Alloy Steel Tubes Welded to an Alloy Steel Flanged Ring as Shown.

Nose Motor Installation Easy.—The Pratt & Whitney Wasp engine construction lends itself readily to assembly on a simple frame because the engine may be divided into units which greatly facilitate installation and assembly or disassembly after installation. The rear sections, of which there are two, the blower and rear, form an assembly by themselves. This makes it possible to divide the engine into two units for assembly as well as service work, the power end consisting of the main case and nose, the shaft, rod, pistons, cylinders and valve gear, and the accessory end, includ-

ing the mounting supercharger and gearing, and all accessories and their drives. Should occasion arise, the "power end" can be removed from an airplane and another substituted without disturbing the "accessory end." This is possible because the engine is supported on the blower section, and the support is arranged as nearly on the center of gravity of the engine, and as far removed from the crankshaft as possible. The weight of a simple engine mount, such as shown at Figs. 765 and 766, made up of alloy tubing

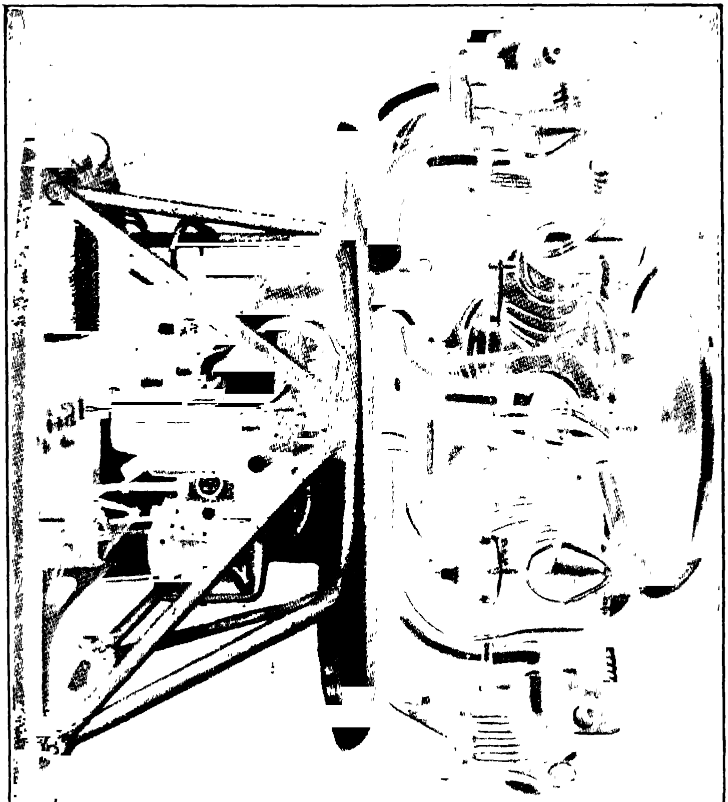


Fig. 766.—Installation of "Wasp" Radial Air-Cooled Engine in Vought "Corsair" Plane is Easily Accomplished by Using the Fuselage Front End Construction Shown Above. Note Simple Attachment of Engine Mount to Front Bulkhead or Fire Wall of Fuselage.

is very small, yet it is extremely strong. It is designed for quick attachment to the fuselage, four bolts being used, one at the apex of each triangular leg. These are secured to fittings projecting through the fuselage bulkhead as shown at Fig. 766.

Outboard or Wing Motor Installation.—When radial cylinder air-cooled engines are carried outboard, instead of being attached to the fuselage nose, as in the two-motor Sikorsky S38 amphibian shown at Fig. 767 or in the Ford and Fokker trimotor, a more elaborate construction is neces-

sary as shown at Fig. 768, which shows an outboard mounting of a Wasp motor in a Fokker monoplane. It will be evident that a separate framework, built up of steel tubing is necessary to carry the motor. This corresponds in general construction to a very short fuselage and usually carries the oil tank in the streamlined tail. Part of the cowling is removed to show how the various engine accessories may be reached. The oil tank location and nacelle or engine framework supporting braces are clearly shown. These are streamline section tubes extending from the front main wing spar to the front of the engine supporting frame and from the rear main wing spar to the midship section of the nacelle frame. The reader's attention is also directed to the method of connecting the exhaust outlets of the cylinders to the exhaust ring and the long exhaust outlet stack at the side of the nacelle which provides silencing action with minimum back pressure.

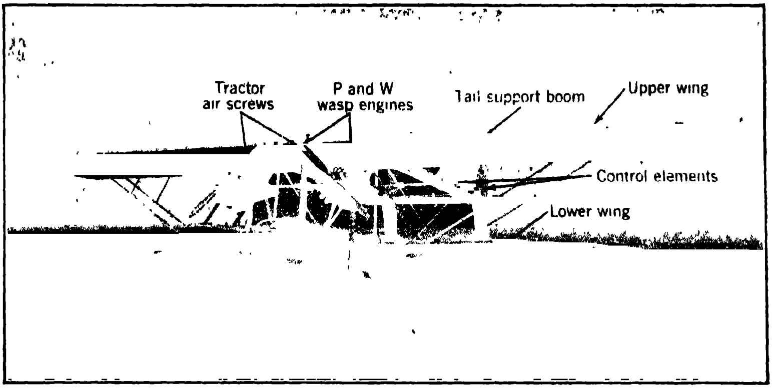


Fig. 767.—Method of Installing Pratt & Whitney "Wasp" Motors on Sikorsky S38 Amphibian in Special Motor Nacelles Between Wings.

Requirements of Engine Mount.—Captain Robert W. A. Brewer, a member of the S. A. E. and an aeronautical engineer of note with much experience on powerplant design and installation, recently published some observations on radial air-cooled engine installations in *Aviation* that should be of interest to the reader. He wrote, in part, as follows:

"In arranging the installation of an air-cooled engine, proper means must be provided for getting rid of hot air readily.

As the type of engine under discussion has so much in its favor with regard to cost of production, ease of overhaul, accessibility, etc., none of these advantages should be minimized by fitting an unsuitable mount and every consideration should be given to this aspect of the subject. There is, at present, no standardized method of mounting. Similar airplanes use different mounts and because the possible adaptations are so wide, we cannot, at this period, set up a standard, and must be content with certain points for guidance.

The engine maker requires that:—

(1) The mount should be light and strong enough to support the engine

without suffering from serious deflection under working conditions. It should be properly braced in all bays.

(2) It must be rigid in itself to withstand the torque variations in the engine and any periodic vibrations in the mounting must not synchronize with any that the engine may have throughout its working range of speed.

(3) The mounting must not set up stresses in the crankcase or in the ends of the fuselage. If attached by pins to the fuselage, the pins should have very ample bearing surfaces and preferably be tapered and ground.

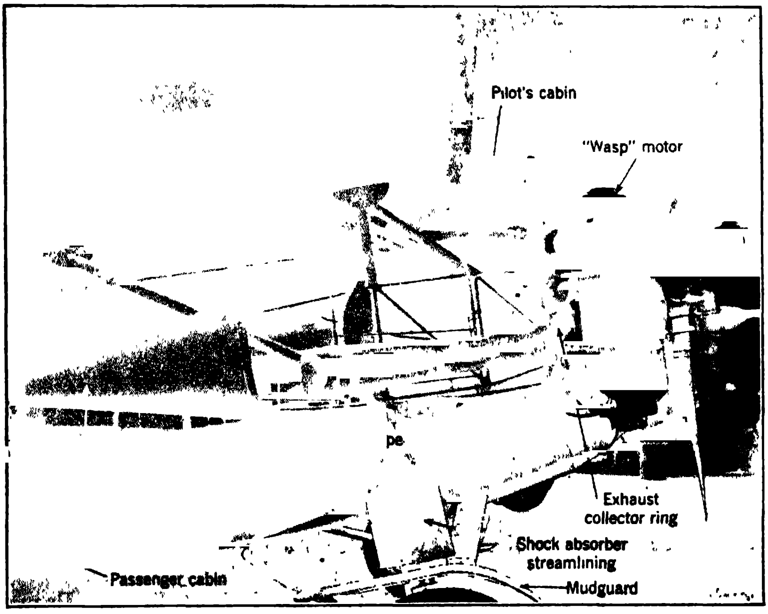


Fig. 768.—Method of Mounting Motor and Supporting Powerplant Nacelle Under Wing of Fokker Trimotor Monoplane. Note Use of Tubing and Method of Streamlining by Sheet Metal Cowling. Illustration Also Shows Method of Exhaust Gas Manifolding.

(4) A spigot mounting plate, if used, should be true and a good fit.

(5) There should be no interference with the accessibility of those parts or details which are likely to require attention periodically. The complete removal as a whole, of the engine and mounting or engine only, should be readily possible. This should only necessitate the disconnection of a few oil, gasoline lines, and the tachometer drive."

The Wright "Whirlwind" motor and motor mount shown at Fig. 769 indicates how this assembly may be removed from the fuselage of a Travel Air plane and all minor connections and instrument board come off with the motor and mounting ring. This is the form where a tubular section ring is welded to triangular leg members, the ring diameter being equal to the engine supporting bolt circle. Attention is also directed to the ex-

haust ring used in this installation and accessibility of the rear of the engine. In some arrangements the mounting ring is removable with the engine as shown at Fig. 769, while in others the ring forms part of the structure and the engine is removable from it. The swinging form of

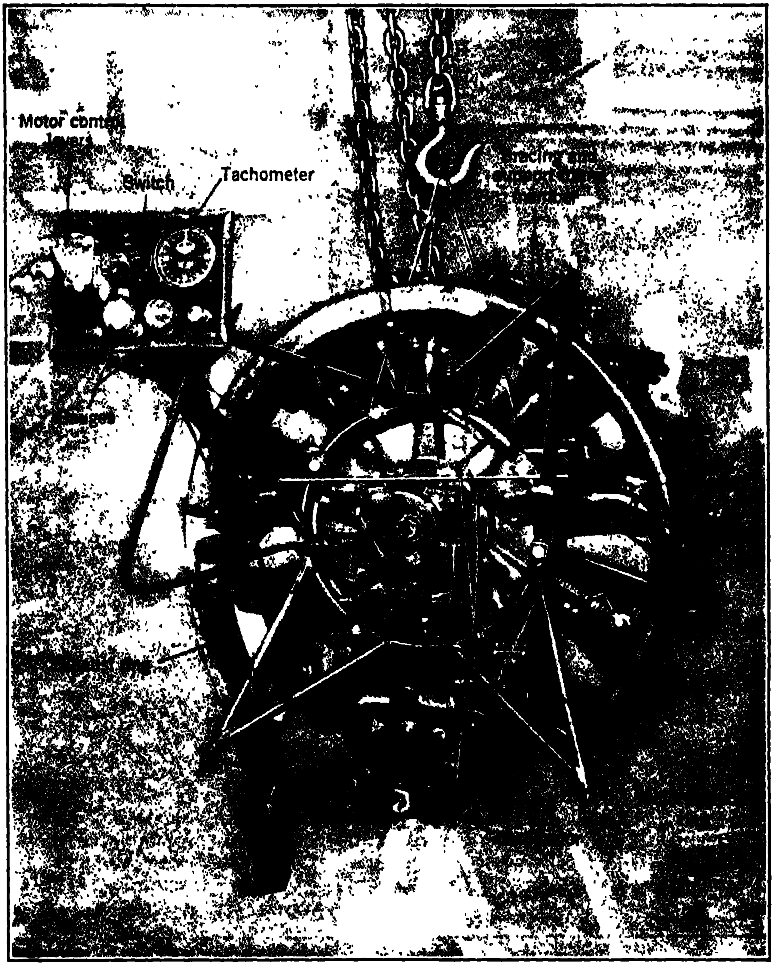


Fig. 769.—Wright "Whirlwind" Motor and Motor Mount of Travel Air Plane Showing Use of Tubing for Engine Mounting Ring. Note Exhaust Manifolding and Instrument Board Mounting. Illustration also Shows Method of Slinging Engine and Mount Unit for Transporting to Fuselage.

front mount is sometimes employed and, although it has not come generally in favor, it shows possibilities. The method of mounting a radial engine outboard is shown at Fig. 768 which also shows cowling and streamlining.

When a radial engine is used as a replacement on a plane designed originally for a straight-line engine, the required center of gravity position

of the plane automatically calls for a considerable space between the rear of the engine and the fire bulkhead. We are thus led to the question of a suitable cowling. Generally, with radials as designed at this time, the forward part of the cowling can be a more or less permanent structure, as the position of the major accessories is usually at the rear. Many radials

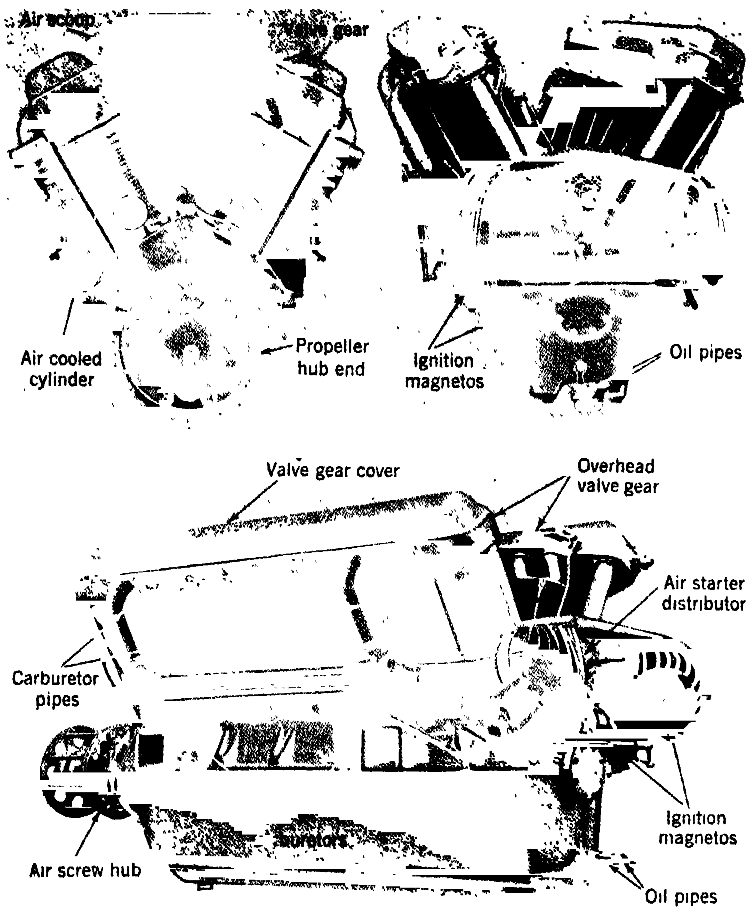


Fig. 769A.—Views Showing the Isotta Fraschini ASSO 450 CA Engine. This Air-Cooled Twelve-Cylinder Vee Type Delivers its Maximum Power at 2,250 R.P.M. and is Designed for Installation in Fighting Planes.

are designed so that the front cover plate gives a good entrant form and scarcely requires a fairing. When this is so, oil-cooling by the slipstream can be taken advantage of. The rear part of the cowling must have easily removable panels between the engine mounting proper and the fire bulkhead. These should have proper stiffness and be so designed that local stresses are not set up as such would cause fracture due to vibration. The

Curtiss Challenger engine mounting shown at Fig. 770 shows modern cowling practice. Generally, this part of the cowling must, in the first instance, be made on the job. The design of proper catches or fasteners leaves much scope for the designer. They should be readily detachable and preferably be some form of safety catch which will stay in place and which can be sunk into suitable depressions in the plates. As to the extent of the cowling and the amount by which it should cover the cooling fins on the engine, much depends upon the kind of general service which the plane will have to fill. Where much ground work and taxiing has to be done, Mr. Brewer believes that the maximum air accessibility is desirable and the engine

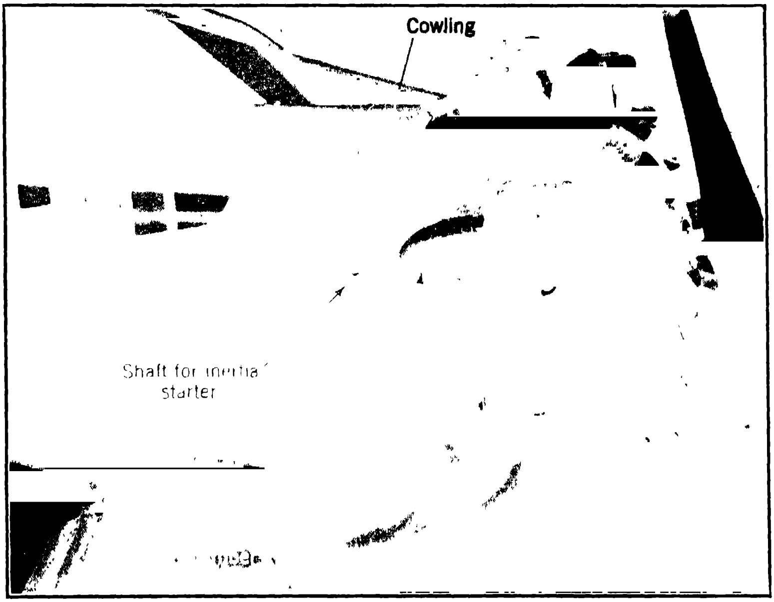


Fig. 770.—Method of Installing and Cowling the Curtiss "Challenger" Air-Cooled Motor in Curtiss-Robin Cabin Monoplane.

may be entirely without cowling. Some engines are too much cooled, so that almost complete cowling has been resorted to. There is an intermediate, and very successful system where helmet cowls are provided for the individual cylinders. They have small front vizors and proper outlets at the rear. It is quite feasible to carry out some scheme such as this not only for individual cylinders but for the engine as a whole.

Disposition of Exhaust Important.—Combined with the matter of cowling, the handling of the exhaust is very important. There are two main considerations here,—nuisance from the noise and prevention of fire. It is apparently a moot point whether the provision of an exhaust ring manifold does or does not diminish fire risk. However, in Captain Brewer's opinion, much depends upon how the stack pipes leave the engine. Certainly the further they are from the carburetor inlet the better, as flame from the exhaust is very readily drawn into the carburetor inlet if it comes at all near to it.

Short stack pipes must be a nuisance to the pilot, particularly in the dusk, and modern progress calls for some form of silencing the noise especially on planes intended for passenger transport. Probably the best place for a ring manifold is in front of the engine and as near to the center as conditions will permit. The design of a suitable system has been full of difficulty and Mr. Roy Fedden, designer of the Bristol Jupiter engine, tabulates some factors to be considered in this connection.

(1) Light weight and the lowest drag possible.
(2) The system must be of sufficient volume not to cause back pressure and damage to the valves.

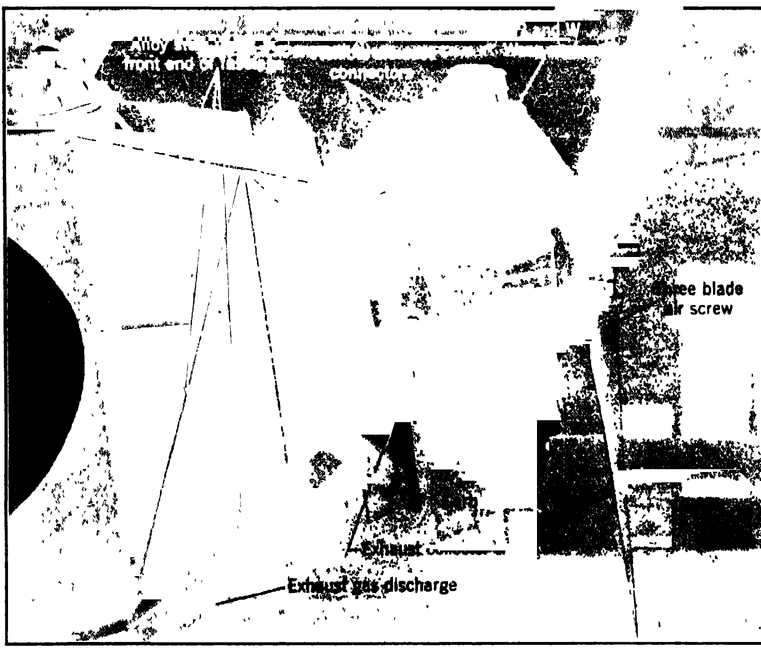


Fig. 771.—Motor Installation to Front End of Fokker Fuselage Showing Motor Cowling and Exhaust Collector Ring. Note Three Blade Standard Steel Propeller.

(3) There must be no sharp bends and the gases must not play directly upon any part of the expansion chamber.
(4) The pipes from the individual cylinders leading to the main chamber must be provided with flexible joints to allow for expansion of the cylinder heads.
(5) Welding to be used as little as possible and if necessary, riveting should be used as well.
(6) The system, as a whole, must be sufficiently rigid to withstand any serious distortion and robust enough for long service.
(7) The design must be such that it can be produced economically by press tools and jigs.
(8) The material must be such that it will resist corrosion.

The general conclusions seem to point to the fact that the exhaust outlet from the engine should be at the side of the cylinder, as from this location the stub pipes can be led forward or back. Proper air cooling of the valve seats can be had, which is more difficult where the pipes lead out directly forward from the cylinder block. Outlets from the exhaust ring can conveniently be two in number,—one on either side near the bottom. By this arrangement the gas can be led away from the carburetor and follow the lines of the fuselage. An interesting study of a practical method of leading away the exhaust gas is that used in the Fokker outboard motor mounting shown at Fig. 768. Here we find a combination manifold consisting of cast

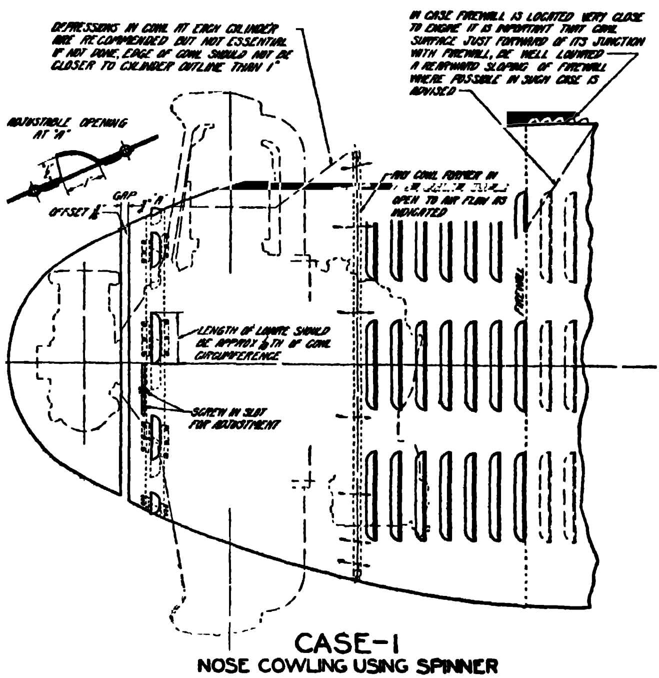


Fig. 772.—Nose Cowling When Propeller Spinner is Employed for Wright "Cyclone" Engine.

elbows at the cylinder heads with cast junction fittings, these being joined together with flexible exhaust tubing, the assembly terminating into a long exhaust discharge pipe carried at the side of the nacelle. Not only are the exhaust gases effectively disposed of and fire risk greatly reduced but a pronounced silencing effect is obtained with minimum back pressure.

The disposition of the exhaust gases in the Challenger-Robin installation is shown at Fig. 770, but in this, the exhaust ring is carried inside the cowling, which some authorities, especially the U. S. Air Service engineers, do not agree with. The exhaust pipes, of which there are two, are siamesed into a muffler appliance carried beneath the cabin. Slip joints are provided be-

tween the cylinder exhaust outlet ports and the manifold pipes, each of which serves three cylinders. Housing in the exhaust ring reduces the parasitic resistance and if the heat can be effectively disposed of, which may be possible by using a large cross sectional area and having the manifold receive some of the air blast through the shuttered openings at the front of the cowling, the neater arrangement may have much in its favor. The mounting of the nose motor on the Fokker trimotor is shown at Fig. 771. This also shows the method of disposing of the exhaust gas by flexible metallic hose connections interposed between the cylinder outlets and the exhaust ring. The general construction is clearly shown in the illustration.

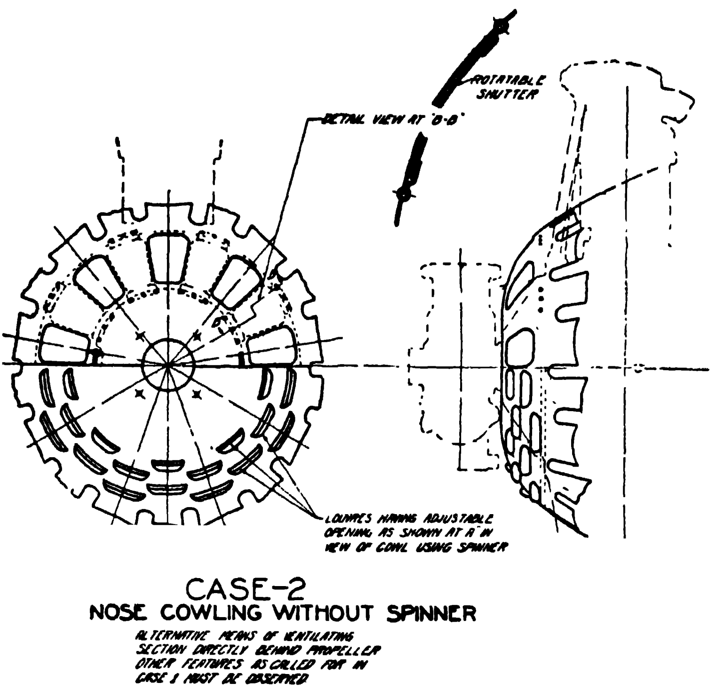


Fig. 773.—Nose Cowling for Use Without Spinner Recommended for "Cyclone" Engine.

Two methods of cowling have been recommended by the Wright Aeronautical Corporation for the Cyclone engine. That shown at Fig. 772 is the type where a propeller spinner is used. Adjustable hooded orifice louvers are placed just back of the spinner, facing the air stream. Outlet louvers, facing the pilot, are placed in the cowling between the fire wall or bulkhead and the engine to permit exhaust of heated air. The alternative means of ventilating the motor section immediately back of the air screw

by nose cowling when no spinner is used is shown at Fig. 773. Details are clearly shown on the drawings.

Cowling for Weather Extremes a Problem.—A big problem that presented itself for solution in designing the Boeing mail plane as stated by Charles N. Monteith, Chief Engineer of the Boeing Airplane Company, Seattle, Wash., was that of cowling for the air-cooled engine; a cowling which would streamline the ragged outline engine as much as possible and at the same time interfere as little as possible with proper cooling. A study

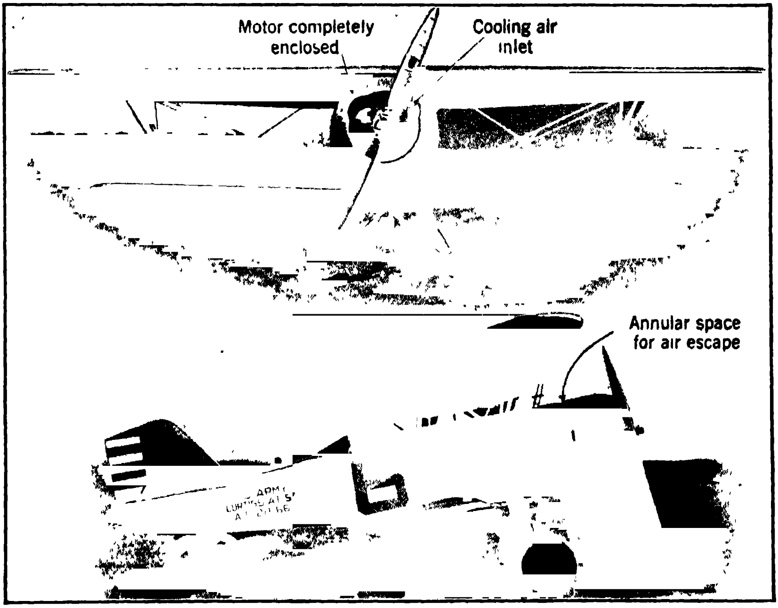


Fig. 773A.—Cowling Developed by National Advisory Committee for Aeronautics Applied to Curtiss AT5 Plane with "Whirlwind" Engine Provides Good Cooling with Greatly Reduced Drag.

of European airplanes, in which the air-cooled engine has been used for some time, gave little help, because the range of cowling designs varied from the one extreme, such as enclosing the engine completely and placing the "crusader" hoods over the cylinder heads, to the other extreme of leaving the engine completely exposed and carrying the cowling down to the mounting plate behind the engine. For the Boeing mail plane, it was decided to adopt the type of cowling used on the Navy X-F3B, a single-seater fighter built by the Boeing Company. It was felt that, as the first few months of operation would be in hot weather, this type of cowling would serve and give time to develop a different type for use in winter. It was found, however, that even the cowling installed was too complete for operation in the hot season, in particular between Cheyenne and Chicago, and it was necessary to remove the circular nose-piece and, in some cases, the pieces between the cylinders. The use of a very heavy oil in the engine was also found necessary. A set of experimental cowling which was carried

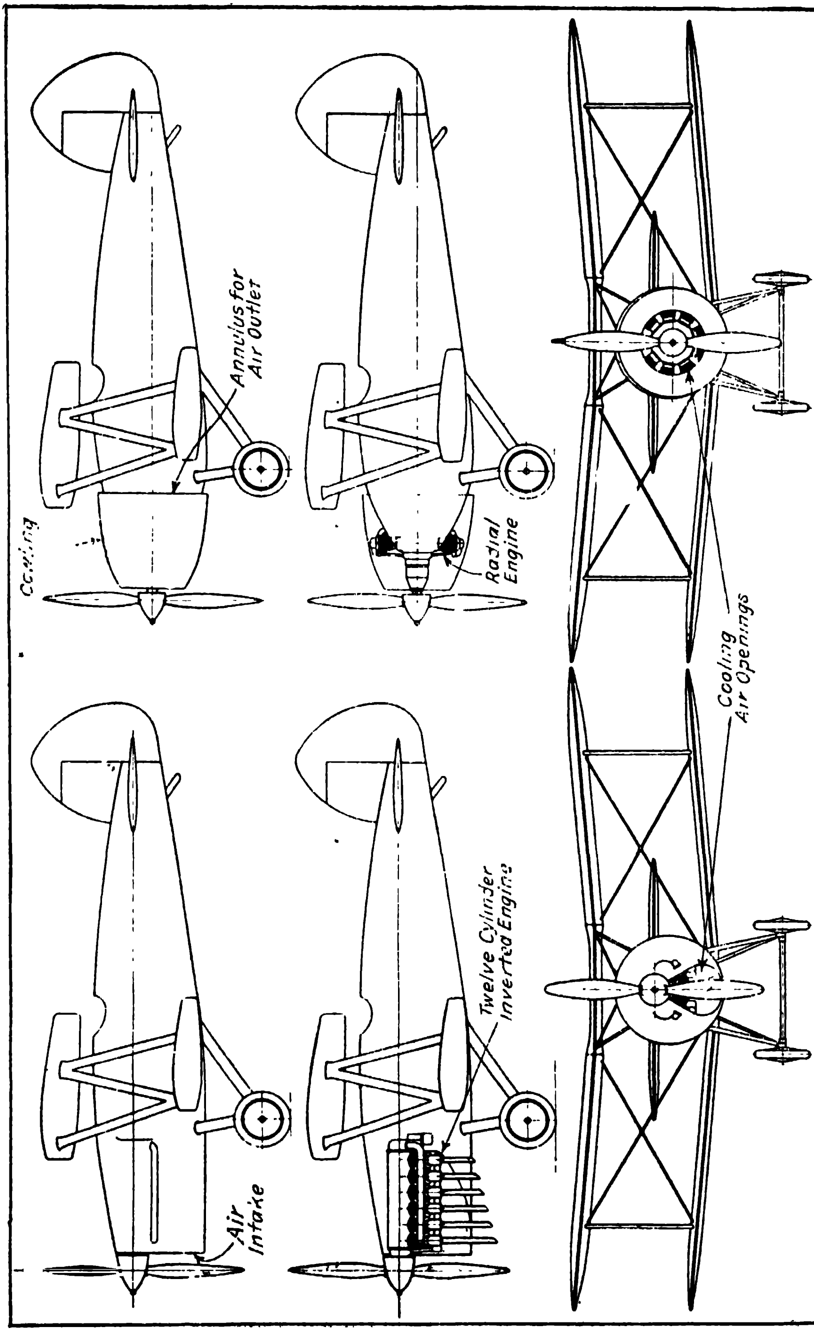


Fig. 773B.—Plate Comparing Installation of Radial and Vee Type Air-Cooled Engines in Airplanes, Showing Arrangement of Cowling to Permit Entrance of Cooling Air Blast Around Cylinders.

to the engine mounting ring, thus leaving the engine entirely exposed, was found to be no better for cooling than the original set without the nose-piece, and to give a decrease in speed as well.

The cowling illustrated in Fig. 774 has been developed for cold-weather flying, and preliminary tests indicate that the oil temperature can be raised at least ten degrees by closing the shutters. It is possible also to keep the oil at a fairly constant temperature for long periods with the engine throttled. The nose plate is rigid, and a second plate mounted inside of it can be moved by a small control operated from the pilot's cockpit. The nine louvers, one in front of each cylinder and of as large a size as the installation will permit, can be closed or opened as becomes necessary. It is hoped

Fig. 774.—Cowling with Adjustable Louvers for Cold Weather.

that this cowling, combined with the air-intake heater, will solve the problem of operation in cold weather, but, until tests under actual service conditions are obtained, no definite conclusions can be drawn as to the value of the device. It was found by actual runs over a speed course that this cowl decreased the speed of the airplane approximately 1.3 miles per hour.

Complete Enclosure Most Efficient.—Development of a new form of cowling for radial air-cooled engines which is said to add more than 30 per cent to the effective horsepower of airplanes in flight was announced recently by the National Advisory Committee for Aeronautics. This accomplishment is regarded by Dr. Joseph S. Ames, Provost of Johns Hopkins University and Chairman of the committee, together with other members, including the experts representing the army and navy, as the most valuable single contribution to airplane efficiency since the war. Costing only about $25 if installed as standard equipment on a plane at the factory, its total cash value to the industry and the public is described by those familiar with the problems of aviation as incalculable. Figured in terms of

horsepower required to produce the increased speed it allows, they estimate that it represents a minimum of $1,500 a plane. By making it possible, in the case of a 200 horsepower engine capable of driving a plane at a rate of 125 miles an hour, the attainment of the same speed at 166 horsepower, it means a saving of three gallons of gas for each hour of flight, they assert.

The new cowling device, which resembles a large bowl with the bottom knocked out to make room for the propeller shaft, is placed over the engine. It is the first result of a cowling and cooling investigation undertaken by the scientific staff of the committee's laboratory at Langley Field, Va., soon after the completion there early this year of the $150,000 propeller research tunnel. In effect, it covers the entire engine, but lets in sufficient air at the front to cool the cylinders. This air flow is controlled in such a manner that it issues from the rear of the cowling in a smooth stream around the fuselage. The device thus cuts down the air resistance, or drag, of the machine in flight while assuring proper functioning of the engine.

Fig. 775.—Experimental Exhaust Manifold Unit with Air Scoop to Reduce Back Pressure by Cooling Hot Gas. This Arrangement is Said to Reduce Flare Appreciably in Night Flying.

The design finally worked out was found to reduce the dragging effect of the engine to 75 pounds at 100 miles an hour, with or without a propeller spinner, as compared with 125 pounds with the engine uncovered. Establishment of the ineffectiveness of a spinner was regarded as facilitating greatly the usefulness of the device by eliminating a complicating element in the repairing of engines. By making the cowling in several pieces, it was explained, it could be readily removed for such work. Flight tests were made with a Curtiss army pursuit training plane equipped with a 200 horsepower Wright "Whirlwind" engine. As heretofore used, with the cylinders jutting out around the nose of the fuselage just behind the propeller, the maximum speed of this machine was found to be 118 miles an hour at 1,900 revolutions a minute. Reporting on the tests after the plane was equipped

with the new cowling, Thomas Carroll, the committee's chief test pilot, declared it had attained a speed of 137 miles an hour at 1,900 revolutions.

Difficulties Presented by Exhaust Manifold.—In the Vee-type engine, with the exhaust ports all in a line, manifolding is relatively easy. With the radial air-cooled engine, the ports are in a circle almost as large as the outside diameter of the engine, and any collector ring placed there lies broadside to the air stream, with the consequent additional resistance. On the military airplanes using this engine, a small individual stack is fitted on each cylinder. On the transport airplane, however, they will not serve in the opinion of Mr. Monteith, because the exhaust manifold must

(1) Eliminate the flash of the exhaust, which, if present, makes night flying in misty weather a hazardous undertaking by blinding the pilot.

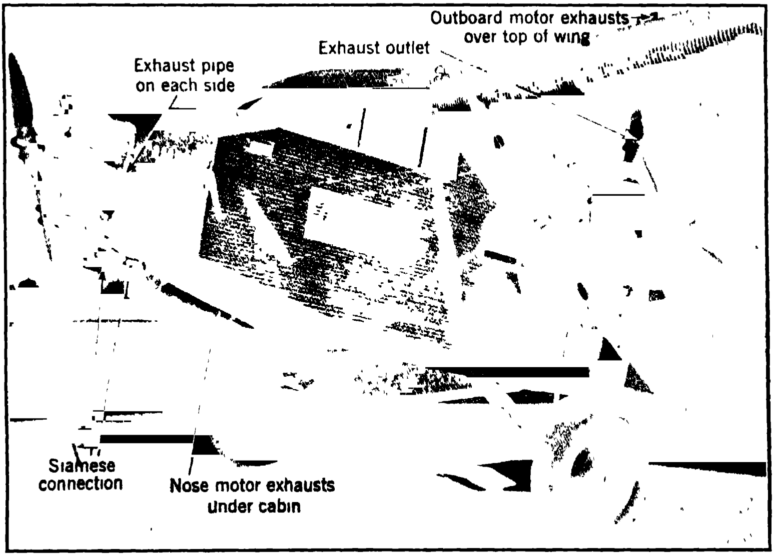


Fig. 776.—Motor Mounting of Ford Trimotor Monoplane Showing How Nose Motor Exhausts Under Cabin and Outboard Motors Exhaust Over Top of Wing.

(2) Muffle the engine to whatever extent is possible. This is essential for the comfort of the passengers, and it lessens the strain on the pilot.

(3) Be jacketed by a stove in cold weather, to provide heat for the passenger cabin, the pilot's cockpit and for the carburetor air.

(4) Conduct all exhaust gases away from the passenger cabin and the pilot's cockpit.

European air-transport practice is almost universal in the adoption of the collector ring terminating in a single or double long pipe under the fuselage. In the case of the Boeing mail plane, one disadvantage of such an arrangement is the location of a gasoline tank in the body. A certain amount of the fuel is almost always spilled when the tanks are filled, and the possibility of this falling on the manifold creates a rather definite fire

hazard. This is minimized, however, by placing the manifold under the fuselage on the side opposite to that on which the filling is done. The method of disposing of the exhaust gases on the Ford trimotor is shown at Fig. 776. The outboard engines exhaust over the top of the wing, the nose motor exhausts under the cabin.

The collector ring manifold has several disadvantages:

(1) It is known to be a definite fire hazard in the event of a crash where gasoline can be spilled on the engine. The manifold can, however, be cooled to some extent by placing a scoop on it, thus forcing a stream of cold air into the exhaust gases. This also assists to some extent in eliminating the flash. Fig. 775 shows an experimental manifold unit with such a scoop incorporated.

(2) It adds considerable weight to the airplane.

(3) It increases the resistance of the airplane because it cannot be placed inside the cowling and should not be laid flat on the outside of the cowling. A stream of air should flow around it to keep it as cool as possible. Tests show that the manifold causes a loss in speed of approximately three m.p.h. as compared with the speed of the plane when the engine is equipped with short individual stacks.

The manifold having two downwardly extending pipes is used at present on the Boeing mail planes. It is not satisfactory because it does not prevent flashing at night. It muffles the engine to some extent, however, and does keep exhaust gases out of the passenger cabin. The diameter of the collector-ring is 3½ inches, and it was feared at first that it would cause too much back pressure; but by actual test, this was found to be 0.4 inch of mercury at full throttle, which pressure occurred at the upper end of the ring. The Pratt & Whitney engineers stated that one inch of mercury was the maximum allowable back pressure. Cabin heating is accomplished by stoves placed around the short stacks at the bottom.

Carburetor Stove for Zero Temperature.—Mr. Montieth stated they had for winter operation, only the experience gained from the Navy fighters using this same engine. It was known that, for operation at air temperatures around zero degrees Fahrenheit, it would be necessary to supply heated air to the carburetor. To do this, the exhaust pipe from the No. 6 cylinder was jacketed with a stove, the heated air from this being led to the carburetor-intake scoop. A valve, controllable from the cockpit, enabled the pilot to regulate the mixture of cold and warm air supplied to the carburetor. While the heater is the best that has been built to date for this engine, it is far from satisfactory, and the Pratt & Whitney engineers, as well as the Boeing organization, are working on the problem. One objectionable feature in this arrangement of the heater is that the exhaust from one cylinder, being independent of the collector ring, makes sufficient noise to be decidedly unpleasant for passengers riding in the cabin and, for the comfort of passengers, this must be eliminated. In Navy tests with the supercharged Wasp, it was found that no carburetor heater was necessary, even at the extremely low temperatures encountered at an altitude of 26,000 feet. This is an additional advantage for this supercharged engine, but it also indicates that the engine might give trouble at the ground in hot weather.

Installing Fairchild-Caminez Engines

Unpacking and Cleaning.—Dimensions of the packing box in which Fairchild-Caminez engines are shipped are as follows:

Height	46¾"
Width	52¼"
Length	54"
Displacement	76¼ Cu. Ft.
Shipping Weight, complete	775 lbs.

Proceed as follows when unpacking:

1. Break seal under metal protecting plates at bottom of box.
2. Remove nuts or bolts under handles and lift cover by handles.
3. Remove oil cloth cover from engine.
4. Remove sparkplugs or dummy plugs from cylinders and rotate engine by shaft until all excess lubricating oil has drained from cylinders.

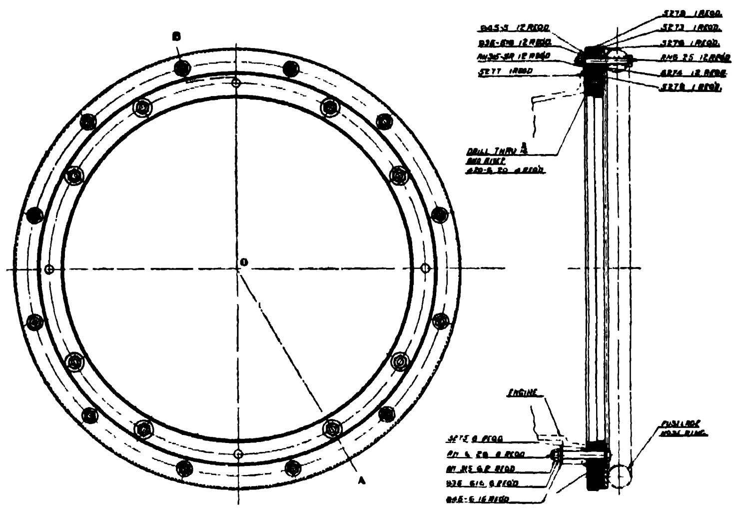


Fig. 777.—Thermoid Engine Mount Assembly for Fairchild-Caminez Engine.

5. Put in sparkplugs. Wash them well in gasoline before screwing them in. Connect ignition wires to plugs.
6. Wash engine complete with gasoline spray.
7. Remove lag screws from mounting plate and raise engine and plate by eyebolt in top of cam case.
8. Take off mounting plate.
9. Clean off back of engine with gasoline spray.
10. Remove covers from mouth of carburetor and exhaust ports.
11. Remove plugs from lubricating oil inlet and outlet nipples and from gasoline connection to carburetor.

Mounting the Engine.—After thoroughly cleaning the engine, bolt the mounting ring to the engine flange with eight ⅜-inch bolts. The inner plain ring should bear directly on the engine base. Do not screw down

too tightly on the nuts. The normal pull on an open end wrench is sufficient. Fig. 777 shows the assembly of the mounting ring and the way it is bolted to the engine and nose ring of the plane. Raise the engine with mounting ring to the center of the nose ring on the plane and work the magnetos back through until the mounting ring is up against the nose of the plane. Bolt the mounting ring to the plane with twelve 5/16-inch bolts. After the plane has been flown for about two hours, pull up on all mounting bolt nuts, after which the nuts will remain tight indefinitely.

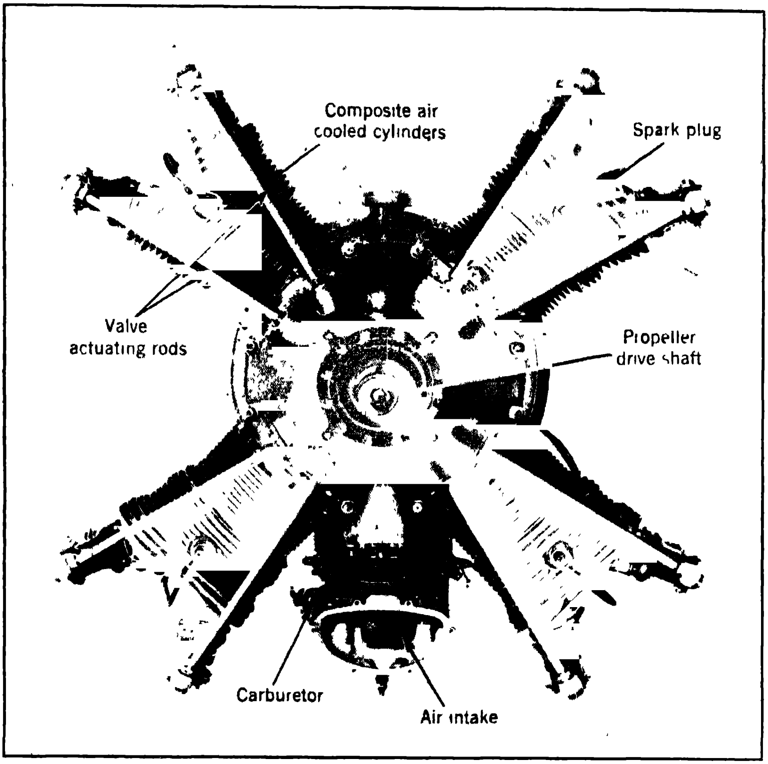


Fig. 778.—Propeller End View of Fairchild-Caminez Motor Showing Carburetor Installation.

The Model 447C engine is supplied with a Stromberg NA-U5 carburetor. Fuel is fed to the carburetor by gravity alone, unless the plane is equipped with an independent fuel pump. The bottom of the fuel tank must be twelve inches above the carburetor at the steepest angle of climb of the ship. Use 3/8-inch copper tubing for the fuel line from tank to carburetor. Place a length of Air Service gasoline hose in the line near the carburetor using a brass hose liner in the joint. Secure the line adequately to prevent vibration. A suitable gasoline strainer should be placed in the line between tank and carburetor in a convenient location for cleaning and draining without removing the cowling. A good strainer made by the Consolidated In-

strument Company of America is shown at Fig. 763.

The carburetor is mounted on the engine with its mouth facing in either direction. No scoop is furnished with the engine but one may be installed without effecting the performance of the carburetor. As shown in Fig. 778, the throttle control lever is on the right side and the altitude control on the left when the carburetor mouth faces forward. The throttle control lever may be set at any angle as it is retained by serrations on the lever and shaft collars. The throttle lever has a radius of 1⅞ inches and moves through an arc of 70 degrees between full open and closed positions. The lever end is ¼ inch thick and is drilled for a ¼ inch clevis pin. The altitude control lever has a radius of 1¼ inch and moves through an arc of 90 degrees between rich and lean. The lever end is ¼ inch thick and is drilled for a ¼ inch clevis pin. For winter flying an air pre-heater should be installed to heat the air coming to the carburetor. This should be arranged to vary the degree of pre-heating so that the air can come direct from the atmosphere or all from the heater.

Lubrication System.—The lubricating oil tank should be of such capacity that there will be two gallons of oil remaining in the tank when the gasoline capacity of the plane is consumed, based on one gallon of oil to twenty gallons of gasoline. If the tank is placed below the center line of the engine, do not drop the oil level more than 24 inches below the pump suction. Expose the bottom or sides of the tank to the slipstream and provide for covering in winter or cover the tank with cowling and provide louvers to allow free circulation of air about the tank.

Vent the tank at the top with a ½-inch copper tube leading to the vent connection in the back of the engine cam case. In winter this vent pipe should be insulated from the cold by asbestos wrapping. The lubricating oil suction and discharge lines are ¾-inch copper tubing. Standard Air Service ¾-inch hose nipples should be placed at each end of the suction and discharge lines with hose liners between pipe ends to prevent sluffing of the rubber into the oil lines. The lines are best left unsupported between the hose nipples. The lubricating oil pump suction is at the left and the discharge to the tank at the right of the engine when observed from the pilot's seat. A thermometer tube location is provided in oil sump of the engine case in front of the carburetor flange. Heat to a low red heat and quench all copper tubing after bending and support all long lines adequately to prevent vibration.

Proper location of the oil tank under the cowling is important, when an engine is installed. The tank should be placed low—the top of the tank should be about level with, or below the center line of the engine and propeller. The bulk of the tank should be considerably below the center line. The filler line can be extended to the top of the cowling, for convenience in filling, and a drain cock can be extended below the bottom cowling. Thus filling and draining can be easily accomplished. It is desirable to have one surface of the tank in the slipstream, or to provide louvers in the cowling below the engine, to allow air to circulate around the oil tank to keep it cool. Oil tank capacity should never be less than five gallons. If large amounts of fuel are to be carried, the oil tank capacity should be seven per cent to eight per cent of the total gasoline capacity. If 100 gallons of gaso-

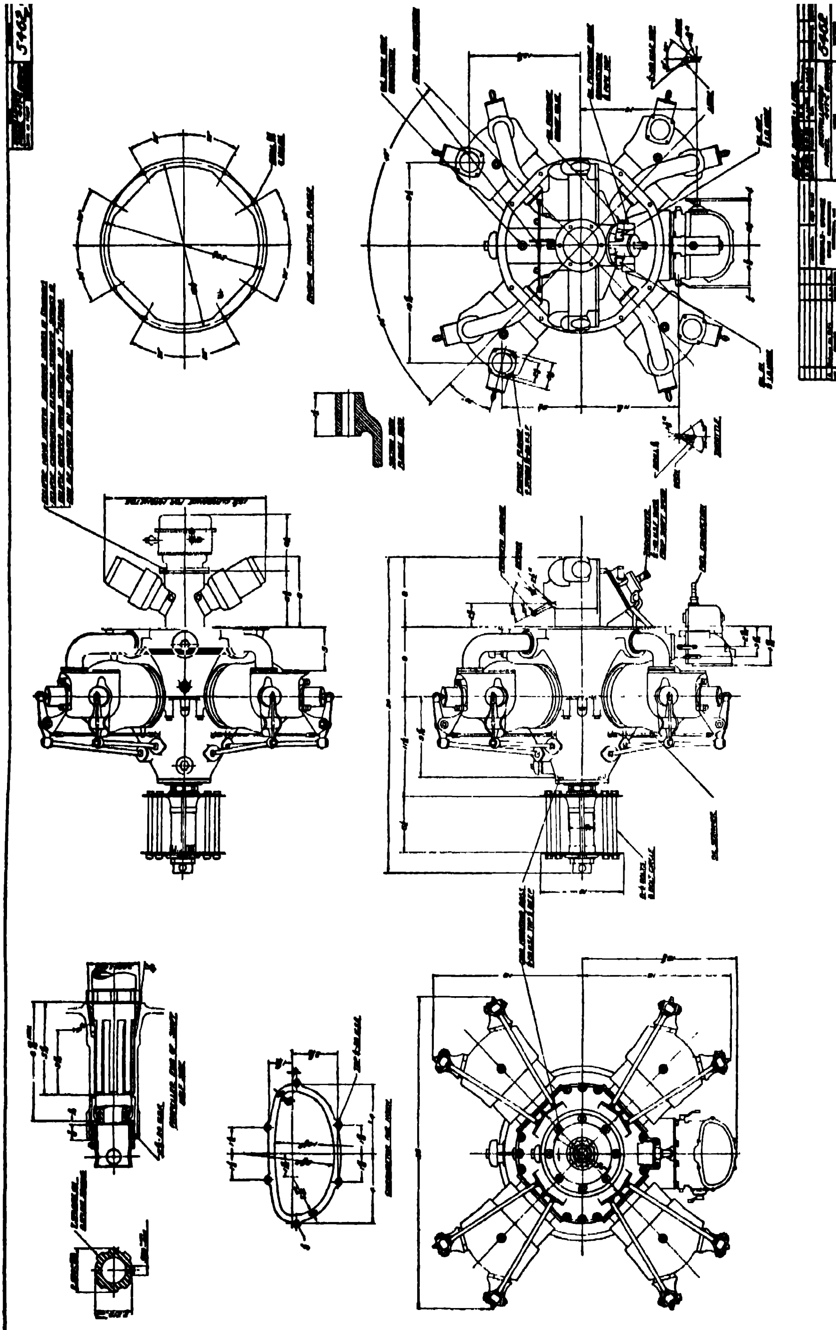


Fig. 779.—Installation Drawings of Fairchild-Caminez Engine.

line are carried, the oil tank should hold about eight gallons of oil. If gasoline capacity is considerably more than this, the oil tank may approach the seven per cent figure rather than the eight per cent figure.

Magneto Wiring.—The magneto connection to the dashboard grounding switch is located directly above the breaker box on the outer end of the Scintilla magnetos. Connect these terminals of the right and left magnetos to the terminals on the switch marked "R. Mag." and "L. Mag." respectively. Use good quality insulated ignition wire and support the wire with clips at suitable points to prevent rubbing and kinking. Connect the switch terminal marked "Grd." or "OFF" to some part of the engine such as the bolts holding the starter. If the engine is equipped with a hand starter with

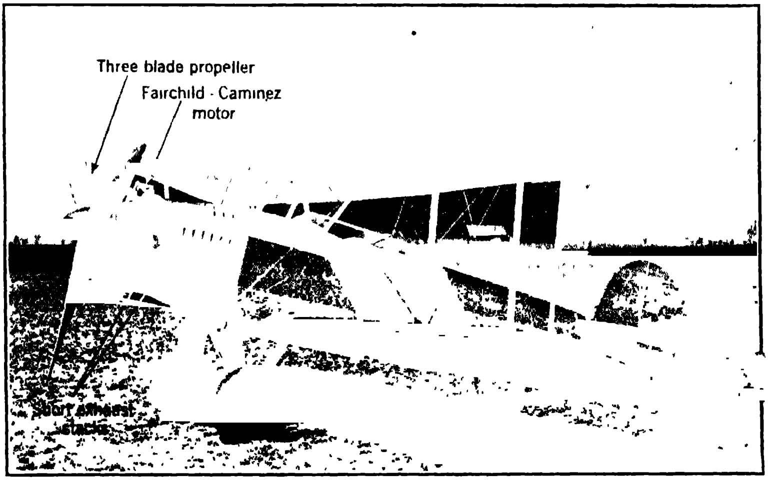


Fig. 780.—Challenger Biplane with Fairchild-Caminez Engine Installed.

booster magneto, connect the terminal on the booster magneto with the terminals marked "H" on the Scintilla magnetos. The upper terminal at the end of the booster magneto is for grounding the magneto when it is desired to crank the engine over without starting. A switch with four terminals or an extra grounding switch will be required on the dashboard. The lower terminal is grounded to the engine and should be connected to the starter stud or some other convenient location.

Spark Control Lever.—The spark control lever is located at the top of the magneto bracket. Its arc of action is 57 degrees and its radius 2¼ inches. It is held in the forward (advance) position by a spring and must be pulled backward (retard) against the spring. The clevis pin hole is ¼ inch diameter.

If the dog on the Eclipse inertia starter or geared hand booster starter is engaged with the extension shaft, the spark control lever will not move. Turn the engine ahead by hand a half revolution which will disengage the dog of the starter. In cold weather when the oil is very viscous, the spark will retard automatically when the engine starts. The spring provided for advancing the magnetos will not operate until the oil is warm enough to

flow freely. Do not attempt to fly until the spark will stay in the advanced position. The engine may also be started by a booster magneto in the pilot's cockpit or by hand cranking the propeller. For hand cranking the propeller mount the propeller with the blades at right angles to the large spline on the shaft.

Tachometer Drive Connection.—A single tachometer drive is located below the lubricating oil pump and is gear driven by the pump shaft. This drive runs at driveshaft or propeller speed in a clockwise direction. With this drive a standard Air Corps tachometer will register twice driveshaft speed. The terminal connection is the U. S. Air Corps standard form with ⅞-inch-eighteen thread. The rated speed of the engine is 1,000 r.p.m. of the driveshaft. This will register 2,000 r.p.m. on the standard U. S. Air Corps tachometer and represents the actual piston speed of the crankshaft speed of an equivalent crank engine. Thus the cam mechanism corresponds to a two to one ratio of a geared crank engine.

Engine Starter.—The engine may be equipped with Eclipse Type M-2,004 Geared Hand Starter with Booster Magneto (gear ratio twelve to one) or Eclipse Series VI. Extension shaft and crank are supplied with the hand inertia starter. An outboard bearing supported from the fuselage members will be necessary to support the extension shaft, and a hole must be cut in the cowling to admit the crank. If the engine is equipped with an inertia starter a push-pull control from the pilot's seat or from the cranker's position must be installed to engage the dog. Make certain that the mechanism springs back positively and allows the starter dog to rest against the leather seat. If the pullrod binds and holds the dog slightly off its seat, oil will seep into the starter flywheel case and cause the starter to work hard.

In building exhaust manifolds for the engine care should be taken not to restrict the flow of the gas or to build up back pressure. All elbows connecting the exhaust ports with the manifold should expand from the two inch diameter port to 2½ or three inches diameter as rapidly as possible and yet clear the flange nuts. The elbow should enter the manifold at an easy angle to allow smooth flow of the gases. The manifold should have an area equal to or greater than a three inch diameter round manifold If the manifold is extended back toward the tail of the ship, the extended length should be expanded to 3½ inch or four inches diameter. If the manifold section is streamlined the cross-sectional area should be larger than that given for round manifolds because of the greater skin friction of the increased surface. Manifold connections are provided with each engine and should be used to mount the exhaust manifolds on the engine.

The shape of the engine cam case lends itself very nicely to the slipstream without cowling completely. If the engine is not cowled complete the cowling should be brought over the mounting flange of the engine. Since each installation is cowled in a different manner it is strongly advised that the airplane builder design his own cowling and submit the design to the engine builder for approval. In general, keep the cowling line below the steel shrink ring of the cylinder. Allow for plenty of air circulation about the cylinder barrel either by cutting louvers or by leaving the cowling open in front of the cylinders. A sufficient number of louvers should be cut in the cowling behind the engine to allow the air to get out.

Propeller.—The choice of the correct propeller is very important. The propeller should not turn above 1,000 r.p.m. (2,000 r.p.m. tachometer reading) at full throttle in level flight. The Installation Department of the engine builders is prepared to forward advice on propellers suitable for various installations. The position of the hub splines with relation to the propeller blades does not affect the running characteristics of the engine. However, for emergency hand cranking, the propeller hub should be placed with the broad spline as nearly 90 degrees to the blades as possible.

Cover all mating parts of the shaft end and hub with graphited grease. The hub cone is easily slid on or off the shaft by expanding it with a screwdriver in the slot. See that the bronze bushing is in the propeller hub or on the shaft cone before mounting the propeller on the shaft. The hub splines should fit the shaft with a secure slip fit. Place a timber on the ground and under the hub nut bar and tighten the nut by pulling down on the propeller blade with the bar bearing on the timber. Tighten the lock nut securely with the special spanner and secure with a cotter pin through the two nuts. Check the propeller for tracking of the blades after it is mounted.

After the hub has been removed and replaced several times the bronze cone bushing becomes thin and allows the hub to press against the camshaft nut. The clearance between hub and nut should be at least .045 inch. If the clearance is too small a new bronze bushing should be used or a hardened washer 1/16 inch to 1/8 inch thick with ground parallel faces inserted between the split steel cone and the camshaft nut.

Installation of "Whirlwind" Engine In the Airplane

Unpacking and Cleaning.—Wright "Whirlwind" engines are shipped from the factory in a sealed packing box with the following outside dimensions:

Height	46¾"
Width	52¼"
Length	54"
Displacement	76½ Cu. Ft.

The shipping weight of the engine and box is:

J4A	970 lbs.
J5	1010 lbs.

The following procedure should be adhered to in unpacking and cleaning a Wright "Whirlwind" engine which is shown in its shipping box with cover compartment of the case removed at Fig. 781.

1. Break seals found under metal protecting plates at the bottom of the box.
2. Remove nuts on four bolts found directly under the handles and lift cover by the handles.
3. Remove oil cloth from the engine.
4. Remove sparkplugs or dummy plugs and turn engine over ten or twelve times to expel oil.
5. Replace sparkplugs. If they were in place in engine when received wash in gasoline before replacing.
6. Remove four lag screws securing mounting plate to bed timbers.

7. Lift engine by passing a rope or cable under the front flange between the bolts of the propeller hub. If a hub is not supplied it will be necessary to proceed in accordance with item 3 below.
8. Remove mounting plate.
9. Remove breather caps and screw in lifting eyes. Lifting eyes are not furnished with the engine but can be purchased from the Wright Aeronautical Corporation.
10. Lower engine on to tilting stand and bolt in place securely.
11. Tilt stand until crankshaft is horizontal.

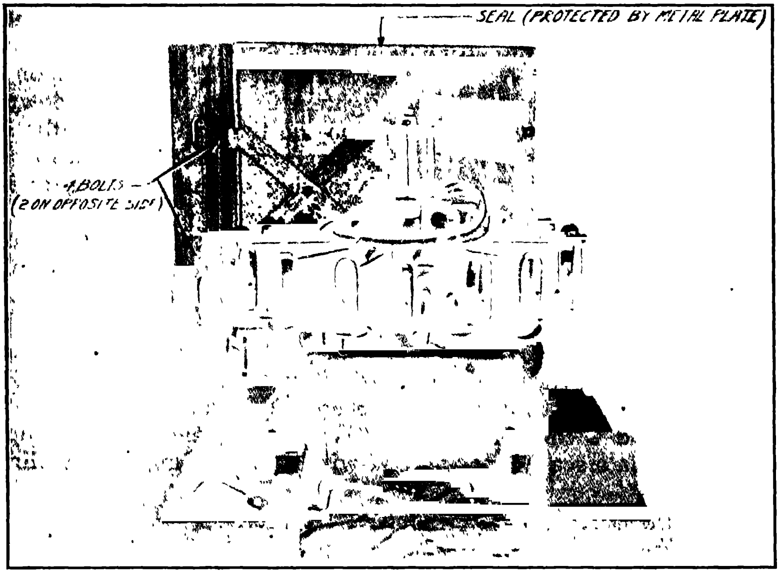


Fig. 781.—Wright Model J5 Engine in Shipping Box with Cover Removed.

12. Clean engine with gasoline spray.
13. Pass a cable through the lifting eyes and hoist engine, removing it from tilting stand.

If a tilting stand is not available proceed as follows:

1. Perform operations 1 to 5 inclusive.
2. Tilt base of shipping box to approximately vertical position and place a support under the propeller hub.
3. Using a piece of rope, make a loop around the base of the No. 3 cylinder inside the push rods, pass both ends up over the hook of a suitable hoist and down around the base of the No. 8 cylinder. Another loop should be put around the hook and the propeller hub or crankshaft end to provide proper balancing. Be sure these ropes clear the rocker arms, sparkplugs and push rods.
4. Lift from floor and remove the base of the engine box.

Installation in Airplane.—After the engine has been unpacked and cleaned it will be ready for installation in the airplane. All burrs and sharp

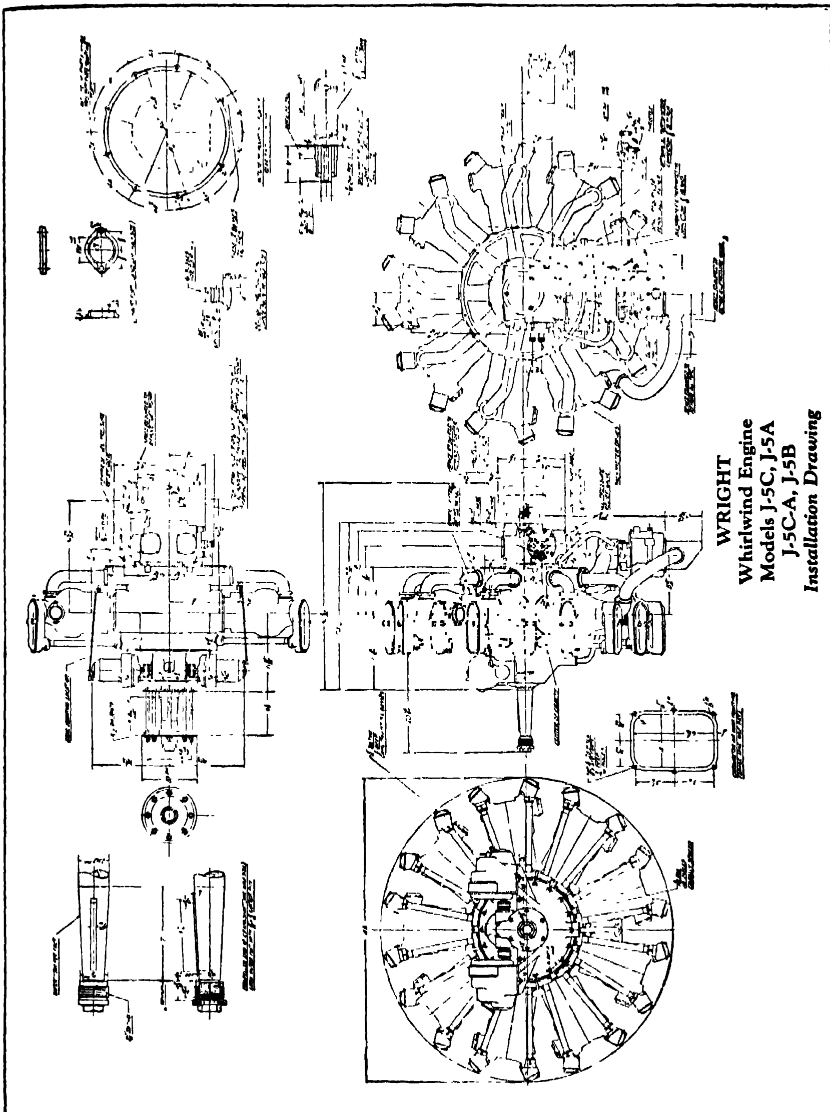


Fig. 782.—Installation Drawing, Wright "Whirlwind" Engines, Models J5C, J5A, J5CA and J5B.

corners should be removed from the engine mount and the mounting flange. Care should be taken to see that the engine mount is flat and fits the mounting flange all around. Hoist the engine by the lifting eyes and carefully work the rear end through the mounting ring. Bolt to the mount securely with eight 3/8 inch diameter SAE alloy steel bolts and lock by some suitable means. The main dimensions of the engine are clearly shown in installation drawing at Fig. 782.

Lubrication System.—The suction pipe from the oil jacketed carburetor manifold to the suction side of the scavenging pump should be installed It is of the utmost importance to see that this pipe is free from air leaks at the flanges. The flanges should be examined to see that they are square and free from dirt and that the gaskets are in good condition before bolting in place. *This is very important as the engine will not function with air leaks in this line.* This oil suction line is clearly shown at Fig. 783.

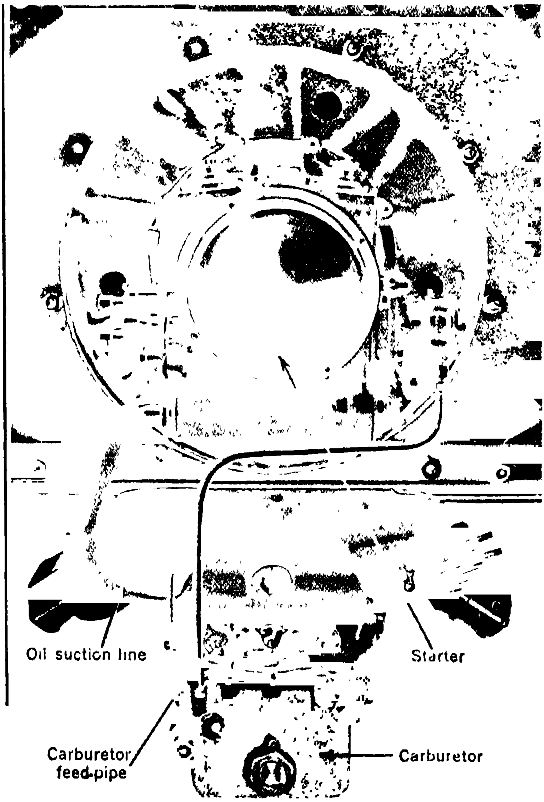


Fig. 783.—Rear View of "Whirlwind" J5 Engine Showing Oil Suction Line and Carburetor Feed Pipe.

The oil tank should, if possible, be located so that the oil level is above the oil pump. This will eliminate trouble with priming. The lines from the tank to the engine should be short with as few bends as possible. Copper pipe of ¾ inch diameter, heated and quenched after bending, and well braced throughout its length to eliminate vibration is recommended. The oil inlet and outlet connections on the engine will be found on the left-hand side of the rear section behind the mounting flange. These are fitted with nipples of the proper size, beaded for hose clamps.

The vent from the oil tank may be piped back into the engine crankcase with a ½ inch diameter pipe. A hole with a ⅜ inch pipe thread is provided on the left side of the rear section of the J5 for this line. This prevents the spilling of oil from the oil tank during stunt maneuvers. The oil pressure relief valve and oil strainer will also be found on the rear section and should be cleaned and adjusted as described later.

The oil pressure line should be ¼-inch copper tubing connecting the pressure outlet, found at the rear and bottom of the rear section, with the pressure gauge on the instrument board. This tubing should be heated and quenched after bending and braced at frequent intervals to eliminate vibration. Brass fittings should be used on the ends of this line.

Ordinarily it will not be necessary to install an oil cooler on "Whirlwind" engines as the heat given to the oil is very small and is easily dissipated from the oil line and oil tank. Under certain extreme conditions a cooler may be necessary, in which case it should be inserted in the discharge line of engine.

Cowling.—Where cowling is provided it is desirable that some provision be made to regulate the cooling obtained by the engine. In cold weather it is essential that the crankcase, carburetors and the lower halves of the cylinder barrels be enclosed to lessen the dangers of cold oil. It is also advisable to lag all the external oil lines with some insulating material, especially the drain from the intermediate section to the sump. For operation in warm weather provision should be made for a sufficiently increased flow of air over the crankcase and cylinder barrels to insure adequate cooling of the engine. The lagging should be removed from the oil lines.

The Wright Aeronautical Corporation encourages airplane manufacturers to send in their powerplant installation designs for criticism. Accompanying the prints should be a general description of the plane, the uses to which it will be put and the climatic conditions which will be encountered. As air-cooled engines are still rather new to most manufacturers, it is hoped they will take advantage of this opportunity and profit by the long experience of the Wright engineers in this line. Various suggestions that have been made for cowling and exhaust gas disposition for air-cooled engines in general will apply just as well to the "Whirlwind" models.

Fuel System.—"Whirlwind" engines are supplied with or without a fuel pump at the option of the customer. If no fuel pump is supplied the carburetor should be connected by a ⅜-inch line of copper tubing, heated and quenched after bending, to a gravity tank having at least twenty inches head. If the fuel pump is supplied, the discharge from the pump is connected by ⅜-inch copper tubing to the carburetor as shown at Fig. 783, the pressure relief is returned to the supply tank and the intake line is taken from the bottom of the supply tank. The fuel lines should be as simple as possible and free from vertical bends in which air pockets can form. The lift from the tank to the pump should not be more than three feet. It will be necessary to prime the engine fuel pump with a suitable hand pump. The engine fuel pump is fitted with a bypass valve which allows the fuel from the priming pump to flow around the pump gear into the discharge line to the carburetor, thus eliminating the necessity for a complicated valve system. To adjust the pressure in the carburetor feed line remove the domed cap from the relief valve, loosen the lock nut and screw in or out on the adjusting screw to raise or lower the pressure.

Magneto Wiring.—The top connections "P" of the magnetos, Fig. 784, should be connected to the points on the grounding switch marked "R Mag" and "L Mag" with insulated ignition wire. The point marked "Grd" on the switch should be connected to the engine crankcase. These wires should all be clipped at suitable points to prevent them from chafing or burning on the engine. This is most important, as the proper functioning of the engine depends on the contacts made through these wires. If an inertia or electric starter is used a booster magneto is not essential but may be

of considerable aid in cold weather. The booster magneto can be mounted in the cockpit, in which case the high tension lead will be connected to the terminal "H" on the top of either magneto. The ground wire from the booster magneto should be connected to the terminal marked "Start" on the switch. If the booster is used from the ground the high tension lead should be inserted in the terminal marked "H" on one of the running magnetos and the body of the booster magneto should be grounded on the engine. In this case the connection can be pulled out as soon as the engine starts and the magneto kept on the ground. Photographs of the running magnetos are given at Fig. 784 showing the starting magneto terminal and

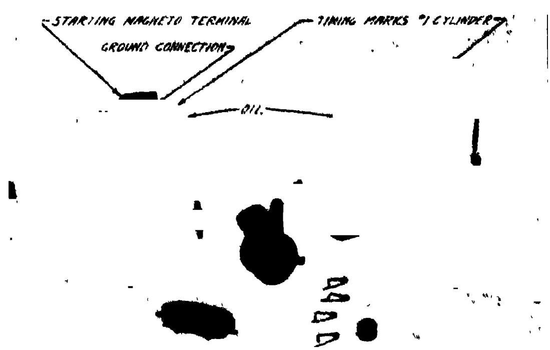
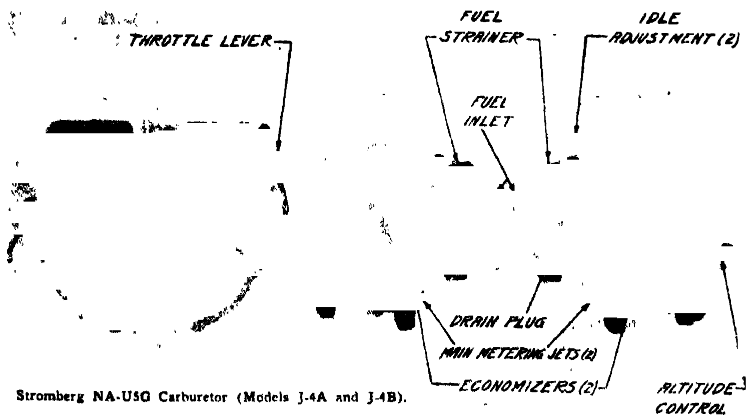


Fig. 784.—Scintilla AG-9D Magneto Used with Wright "Whirlwind" Engines.

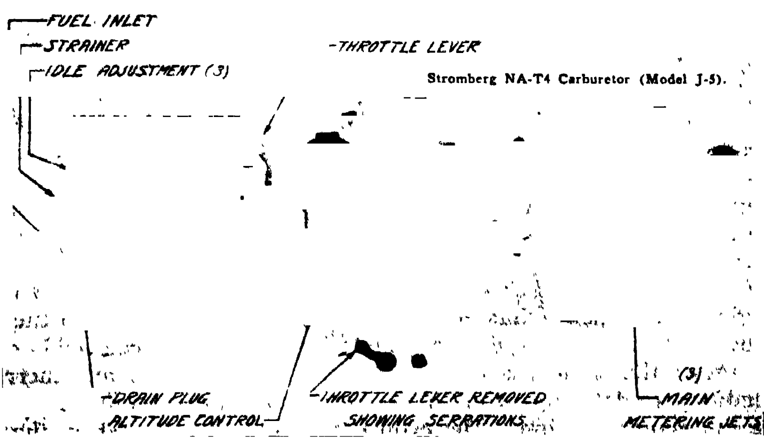
ground connection. The spark control levers on the magnetos are connected by rods, ball joints, and levers to a cross shaft running through the rear part of the crankcase. The left end of this shaft is provided with a lever to which the control rod is to be attached. The movement of this lever is 72 degrees, the radius is 1$\frac{7}{16}$ inch, and the hole in the end is drilled for a $\frac{3}{16}$-inch pin.

"Whirlwind" Carburetor.—The carburetor is adjusted at the factory to give the proper fuel consumption when mounted on the engine facing the rear with no air scoop. If an air scoop is added or the carburetor is faced forward, the fuel characteristics of the engine will be changed and a further adjustment may be necessary. It is, therefore, recommended that the carburetor installation be left as received. In case a change is necessary, the company's Service Department should be consulted. The controls on the J4B engine are on opposite sides of the carburetor—the throttle on the right and the mixture control lever on the left. The throttle lever can be adjusted to any position by removing the cotter pin and nut on the end of the throttle shaft and moving the lever on the serrations to the desired angle, then replacing the nut and cotter pin. Do not draw up this nut too tightly as it will shear the shoulder on the throttle shaft and cause it to bind. The throttle lever cannot be moved from one side of the carburetor to the other. It has a radius of 1$\frac{7}{8}$ inch and a travel of 70 degrees between full open and full closed. Both throttle and mixture levers are drilled to .218 inch, the

throttle lever being ¼ inch thick and the mixture lever 5/32 inch thick. Clockwise rotation of the lever opens the throttle and counter-clockwise closes it. The mixture control swings through an angle of 90 degrees on a 1¼ inch radius. Clockwise rotation of the lever is full rich and counter-clockwise full lean. The mixture control operates from 45 degrees below horizontal to 45 degrees above horizontal. This movement can only be changed by fitting a special lever. In fitting a special lever, care should



Stromberg NA-U5G Carburetor (Models J-4A and J-4B).



Stromberg NA-T4 Carburetor (Model J-5).

Fig. 785.—Stromberg Carburetors Used with Various Models of Wright "Whirlwind" Engines.

be taken to see that the mixture control valve is not shifted from its proper position. The fuel pressure line connection should be made at the drain hole in the wall of the carburetor strainer chamber. When received this hole will be stopped with a plug stamped "Drain." Photographs of the Stromberg NA-U5G carburetor will be found at the top of Fig. 785.

The float chamber of the J5 carburetor is so arranged that the gasoline will approximate normal head when the ship is thrown from the catapult

or goes through stunt maneuvres. It is, therefore, inadvisable to turn the carburetor around as this will upset these conditions. The throttle and mixture control levers of the NA-T4 carburetor are both on the right-hand side and neither can be shifted to the other side The throttle lever, as on the NA-U5G carburetor, can be adjusted to any desired angular position and has a movement of 70 degrees between full open and full closed. The mixture control lever is in the full rich position at 34 degrees aft of the vertical and full lean at 21 degrees forward of the vertical. The radius of both levers is 1⅜ inches and both are drilled for a 3⁄16-inch pin. The throttle lever is .248 inch thick and the mixture control lever is .186 inch thick. The fuel pressure gauge line connection should be made at the drain hole in the wall of the carburetor strainer chamber. When received this hole will be stopped with a plug stamped "Drain." Photographs of the NA-T4 carburetor will be found on Fig. 785, at the bottom of the illustration.

Tachometer Drive Connection.—The two tachometer drive connections will be found on top of the oil pump on the left-hand side of the rear section. These are of the U. S. Air Corps standard form with ⅞-inch—eighteen thread. They rotate at ½ crankshaft speed in a counter-clockwise direction as viewed from the open end.

Starter.—Several types of starters are supplied on J4B and J5 engines as desired by the customer. On all starters a hand crank is required which fits over a shaft and drives through a pin. In most cases the hand crank is supplied with the starter but it may be necessary to change its length to suit various installations. An outside bearing in line with the starter shaft will be necessary. This bearing should be rigid and have sufficient clearance to allow for a slight misalignment of the hand crank and starter shaft. With the inertia starters a push-pull control is necessary to operate the engaging dog. This control can be led to the pilot's seat or brought out near the crank. It is necessary to push the control if the engine fails to start in order to disengage the clutch. A rod mechanism is therefore essential. The same installation is required with the worm type of starter. If for any reason the starter dog is removed and not replaced, dummy parts will be required in the crankshaft to seal it against engine oil pressure.

Mounting the Propeller.—The propeller should be designed to allow the engine to turn approximately rated speed at full throttle when the ship is in level flight. Other speeds are undesirable as low speed holds down the power of the engine, causes excessive torque vibration and increases the tendency to detonate, while high speed subjects the engine to strains which will shorten its life. The propeller should be installed on the hub with the dowel in the line of the blades. In this position the propeller blade marks top and bottom center of No. 1 cylinder. With the hub placed on an arbor the propeller should be set on parallels to check the balance. The propeller should also be checked for track, i.e., the following of one blade in the plane of the others. This can be done most easily in the ship by establishing a point on the plane close to the propeller tip and checking the distance to each blade as it passes this point. No propeller which is out of track or balance should be used. When mounting the propeller the taper and threads on the crankshaft should first be cleaned with gasoline and blown off with an air hose if available. The same treatment should be given

the bore of the propeller hub and the crankshaft nuts. The crankshaft should then be coated with engine oil or graphited 600W and the propeller hub pushed on. The inner nut should be screwed onto the crankshaft until it is home. It is advisable to hit the propeller hub wrench three or four times with a lead hammer to be sure that this nut is tight. The outer nut should then be screwed into the hub and the same procedure followed. Be sure that these nuts are clean and well oiled before installing. A hole in the inner nut must register with a similar hole in the outer nut to take a cotter pin for locking. There are twelve holes in the inner nut and two holes spaced 45 degree apart in the outer nut so it is a fairly easy matter to bring the nuts together for a cotter pin. Turn the engine over a few times by hand to make sure that the propeller has ample clearance at all points.

Wright "Whirlwind" Engines

Instructions for Starting and Normal Operation

Before starting the engine for the first time the following items should be checked:

1. Check over all nuts and bolts both on the engine and the mount and see that they are tight and properly locked
2. Check the propeller hub nuts to be sure they are tight and cottered.
3. Lubricate the valve gear with Alemite gun using 600W oil.
4. Fill the oil tank with an ample quantity of oil for the run (minimum quantity two gallons) and see that all lines are open.
5. Fill the gasoline tank with the proper grade of gasoline.
6. Operate the throttle and mixture controls and inspect the levers on the carburetor to make sure that they hit the stop on both ends of the travel without restriction.
7. Operate the spark advance control and inspect for full operation of the lever.
8. See that the tachometer and pressure gauge are properly connected and that the oil temperature thermometer bulb is in place.
9. Turn the engine over by hand to see that everything is clear.
10. See that the priming line and pump are properly connected and in working order.
11. Open the cocks in the gas line and operate the hand pump if supplied. See the gasoline is supplied to the carburetor and that all lines are tight. See that the carburetor does not drip gas.
12. See that ground wires are connected to the magnetos.

Starting.—Having completed the pre-starting inspection the engine is ready to start and should be handled as follows:

1. Give the engine several strokes of the priming pump. Experience is necessary to determine the proper amount of prime for each engine. About five or six strokes of the Lunkenheimer pump are usually necessary. Excessive priming has a tendency to wash the oil off the cylinder walls and cause scoring or seizing of the sleeves and pistons. In cold weather the engine requires more priming than in warm weather.

   A hot engine does not ordinarily require priming.

2. Turn the engine over a number of times with the throttle closed to suck the gas into the cylinders.
3. Set the throttle to approximately 1/8 open and the mixture to full rich. Easier starting will be obtained with spark control at approximately full advance.
4. Operate the starter and allow the engine to turn over a full revolution. Then turn the ignition switch to the start position and operate the booster if one is being used.
5. If the engine fails to start after several attempts prime again and repeat. If the engine is overprimed the throttle should be opened wide and the engine turned backward several revolutions by hand. Be sure the ignition switch is off.
6. In extreme cold weather the oil should be heated before filling the oil tank.

If the engine fails to start after a reasonable number of attempts, consult special chapter on troubles and overhauling to ascertain possible cause.

Ground Test.—When the engine starts the spark should be advanced, the throttle pulled back to 600 or 800 r.p.m. and the gauge watched for oil pressure. If the oil pressure fails to rise within one minute the engine should be shut down and an investigation made. After the gauge indicates oil pressure the engine should be run at 600 to 800 r.p.m. for two minutes or more and the throttle then opened to 1,000 r.p.m., where it should be held until the oil outlet temperature starts to rise. The speed may then be increased slowly to full throttle. The mixture control should be leaned out until the engine is turning maximum r.p.m. This may occur in the full rich position. Observe the r.p.m., oil pressure and oil temperature. With the mixture control set for maximum r.p.m., check the functioning of the engine when running on one magneto at a time. If the values observed are normal and the speed does not drop more than 75 r.p.m. on each magneto the engine is ready to fly. It should be remembered that the engine receives very poor cooling while on the ground and prolonged running at full throttle should be avoided.

Flight.—The instruments should be noted at frequent intervals to see that the powerplant is functioning properly. The engine should be operated to keep within the following limits:

Oil pressure 50 to 75 pounds per square inch.

Outlet oil temperature not over 180 degrees Fahrenheit (82 Centigrade).

Fuel pressure two to four pounds per square inch.

If the oil pressure falls below 35 pounds an immediate landing should be made and the cause of the trouble located and removed. It is not so serious when the oil pressure exceeds the high limit but it should be corrected at the end of the flight. This can generally be done by adjusting the relief valve. High oil temperature when not caused by atmospheric conditions may be a sign of trouble in the engine. If the outlet oil temperature rises above 180 degrees Fahrenheit a landing should be made as soon as possible and its cause determined and corrected.

Landing.—Because of the faster heating and cooling rate of air-cooled engines a hot engine should never be shut down rapidly, except in emergencies, as this is almost sure to warp the valves. After a plane has landed

and taxied to the line, the spark should be retarded, the throttle slowly closed to 600-700 r.p.m., and the gasoline supply shut off. The engine should be allowed to run this way until the fuel supply fails. If this is done regularly the time between overhauls will be greatly increased.

Fuels.—The fuel used should be either of the type known as Grade B domestic aviation gasoline or one of the commercial fuels recommended. The use of other fuels is apt to lead to unsatisfactory operation and serious damage to the engine. The manufacturer will assume no responsibility for the engine's performance when other fuels are used. In case of emergency, when approved gasoline is not available, benzol gas, ethyl gas or high test automobile gasoline should be used. The engine should then be operated at reduced throttle with the mixture control in the full rich position. Gasoline from California base crudes is much superior to gasoline from the mid-continent and eastern crudes.

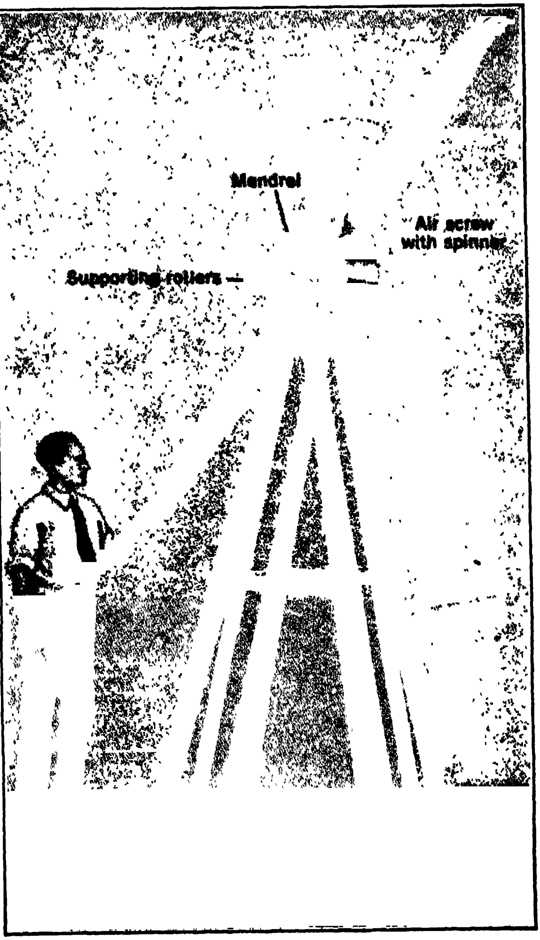


Fig. 786.—Method of Balancing a Wright "Whirlwind" Engine Propeller. Stand Shown Can be Used with Any Propeller it Will Swing.

The following specification corresponds to the Navy Department Specification No. 7G1 B of December 1, 1924, for Grade B domestic aviation gasoline.

Grade B, domestic aviation gasoline shall conform to the following requirements:

1. The gasoline shall be free from water and suspended matter.
2. Color. — The color shall not be darker than No. 25 Saybolt.
3. Doctor test.—The doctor test shall be negative.
4. Corrosion test.—One hundred cubic centimeters of the gasoline shall cause no gray or black corrosion and the amount of deposit when evaporated in a polished copper dish shall not exceed three milligrams.

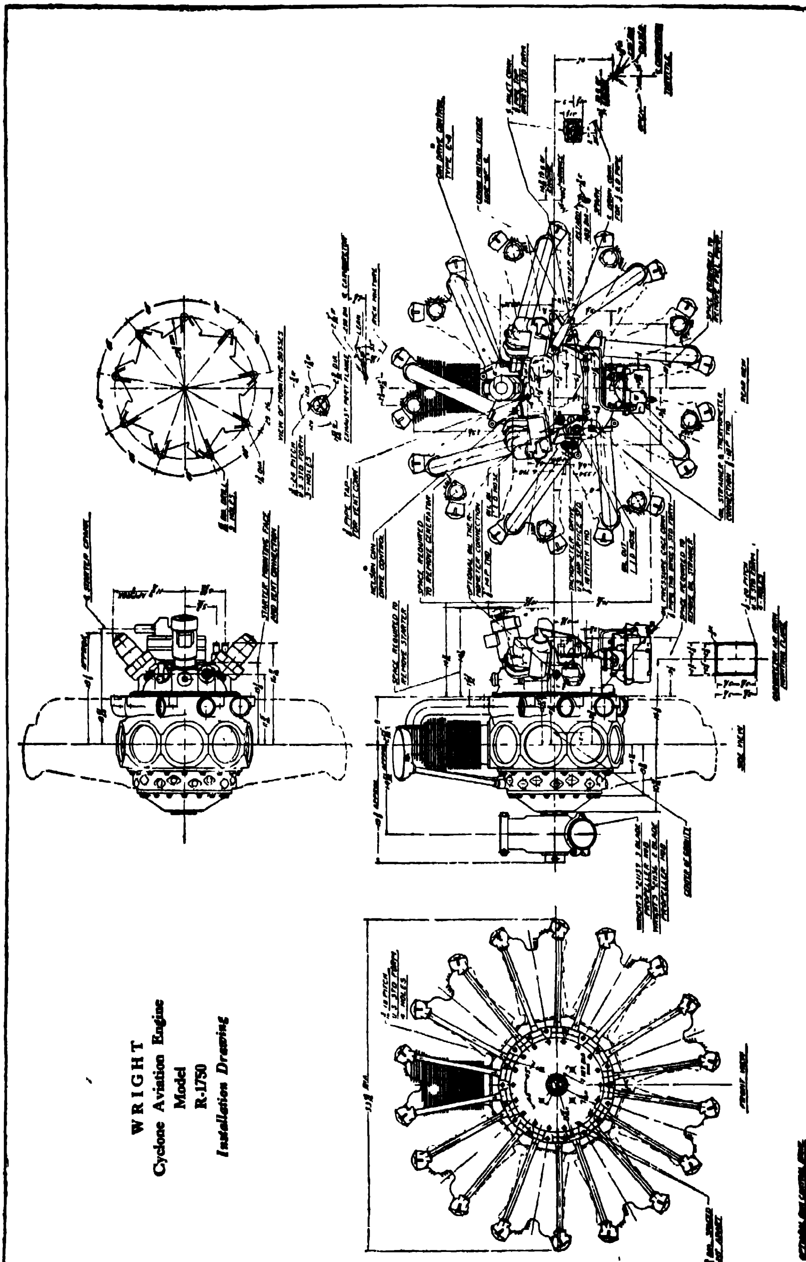


Fig. 787.—Installation Drawing of Wright "Cyclone" Aviation Engine Model 1750.

5. Distillation range.—The temperature limits are as follows: When five per cent of the sample has been recovered in the graduated receiver, the thermometer shall not read more than 75 degrees Centigrade (167 degrees Fahrenheit), or less than 50 degrees Centigrade (122 degrees Fahrenheit).

   When 50 per cent has been recovered in the receiver, the thermometer shall not read more than 105 degrees Centigrade (221 degrees Fahrenheit).

   When 90 per cent has been recovered in the receiver, the thermometer shall not read more than 155 degrees Centigrade (311 degrees Fahrenheit).

   When 96 per cent has been recovered in the receiver, the thermometer shall not read more than 175 degrees Centigrade (347 degrees Fahrenheit).

   The end point shall not be higher than 190 degrees Centigrade (374 degrees Fahrenheit).

   At least 96 per cent shall be recovered as distillate in the receiver from the distillation.

   The distillation loss shall not exceed two per cent when the residue in the flask is cooled and added to the distillate in the receiver.
6. Acidity.—The residue remaining in the flask after the distillation is completed shall not show an acid reaction.
7. Sulphur shall not be over 0.10 per cent.

Oil.—Lubricating oils for use in Wright engines must conform to the following specification:

1. Flash point—Method 110.31. The flash point shall not be lower than 400 degrees Fahrenheit.
2. Viscosity—Method 30.4. The viscosity for summer use shall be 90 to 105 seconds and for winter use shall be 75 to 85 seconds.
3. Pour points—Method 20.11. The pour point for summer use shall be less than 45 degrees Fahrenheit and for winter use shall be less than fifteen degrees Fahrenheit.
4. Acidity—Method 510.3. Not more than 0.10 milligram of potassium hydroxide shall be required to neutralize one gram of oil.
5. Emulsion test—Method 500.11. The oil shall separate completely in one hour from an emulsion with distilled water at a temperature of 180 degrees Fahrenheit.
6. Carbon residue—Method 500.11. The carbon residue shall not exceed 2.5 per cent.
7. Precipitation number—Method 310.1. The precipitation number shall not be greater than 0.5.
8. The oil shall be derived from a petroleum base and shall be free from fatty oils, resins, soap and other compounds not derived from petroleums.

Tests—All tests shall be made in accordance with "Method for Testing Lubricants and Liquid Fuel" contained in Technical Paper No. 323A, Bureau of Mines. The method numbers given above refer to this

paper. Copies of this paper may be obtained upon application to the Quartermaster General, U. S. Army.

The lubricating oils listed below have demonstrated by extensive service that they are satisfactory for use in Wright engines.

Summer Grade	Winter Grade
Gargoyle Mobiloil B (97-101)	Gargoyle Mobiloil BB (75)
Hyvis Extra Heavy (110)	Hyvis Special Heavy (85)
Kendall G (106)	Kendall F (87)
Marland Super Liberty (100)	Marvelube Special Heavy (75)
Marvelube Extra Heavy (103)	Pennzoil Extra Heavy (85)
Pennzoil Aviation Special (100)	Stanolind Superla (80-85)
Stanolind Superla (90-95)	Veedol Special Heavy (74)
Valvoline Special Heavy (95)	Warren A B C
Veedol Extra Heavy (106)	Zerolene Aero—1 (80)
Wolfshead No. 8 (98)	
Zerolene Aero—2 (95)	

Numerous engine operators have shown an inclination to use a heavier summer oil than the grade recommended by the Wright Aeronautical Corporation. This practice has met with success during warm weather and is permissible if desired. The following brands of oil have been used with satisfaction.

Kendall J (125)
Magnoline (125-130)
Pennzoil Double Extra Heavy (115)
Stanolind Aero (125)
Valvoline Extra Heavy Special (122)
Veedol Liberty Aero No. 4 (116)

When a heated hangar is always available, or some method of preheating the oil is employed, it is possible to use an oil of summer grade during the winter time if desired **but this practice is not recommended.** Better satisfaction will be obtained with one of the winter grade oils listed above. **The oils listed for warm weather should not be used during cold weather under any condition.** In all the tables given above the oils are listed in alphabetical order and not in order of merit as good results are obtained with all of them. The figures in parentheses are the viscosities at 210 degrees Fahrenheit.

Unpacking and Cleaning Cyclone Engine.—Wright Cyclone engines are shipped from the factory in a sealed packing box with the following outside dimensions:

Height	49⅛ in.
Width	58 in.
Length	61¾ in.
Displacement	100 cu. ft.

The shipping weight of the engine and box is approximately 1,530 pounds.

The following procedure should be adhered to in unpacking and cleaning a Wright Cyclone engine:

1. Break the seals found under the metal protecting plates at the bottom of the box.
2. Remove the nuts on the four bolts found directly under the handles

and lift the cover off by the handles.
3. Remove the oil cloth from the engine.
4. Remove the sparkplugs or dummy plugs and turn the engine over ten or twelve times to expel the oil from the cylinders.
5. Replace the sparkplugs. If they were in place in the engine when it was received, wash them in gasoline before replacing.
6. Wash the packing grease off the engine using a gasoline spray. A clean paint brush and a bucket of gasoline will serve the same purpose if a spray outfit is not available.
7. Screw a pair of hoisting eyes WA-236 into the two holes provided in the crankcase on either side of No. 1 cylinder and prepare to lift the engine with a chain hoist and rope. It is very desirable to put a spreader between the two ropes to keep them clear of the No. 1 cylinder.
8. Lift the side of the box base at the top of the engine until the ropes are sure to clear the No. 1 cylinder and then raise the engine and base to a vertical position with the hoist. Rig another sling between the crankshaft and the hoist hook to keep the engine in a vertical position when hanging free.
9. Remove the nuts from the ten bolts holding the steel mounting plate to the base and remove the base. The mounting plate can then be removed from the engine.

Engine Mount and Cowling.—As each airplane presents its own problem in the way of engine installation, it is impracticable to give more than a generalized recommendation. It is the belief of the makers that from the standpoint of weight, strength, rigidity, accessibility and cost, the tubular engine mount structure is the most satisfactory type developed up to this time. In the design of such a mount it is desirable that the arrangement of members be such as to produce direct stresses only, that is, tension or compression without bending. The Wright Aeronautical Corporation will furnish upon request drawings showing engine mount structures of this type which have proved satisfactory in service and the reader can study various engine mounts presented at the beginning of this chapter for further detailed suggestions.

In designing cowling it should be borne in mind that it is practically impossible to overcool the cylinder heads and cylinder barrels. For cold weather operation, it is essential that the crankcase be protected to prevent excessive cooling of the oil. In operating in hot weather, however, it is necessary to circulate air around the crankcase. Inasmuch as it is generally desirable, from the standpoint of appearance and performance, to carry the general line of cowling above the base of the cylinders, it is necessary to introduce the air for cooling the crankcase and lower portions of cylinder barrels through holes or louvers in the nose cowling. In order to take care of varying temperature conditions it is advisable to provide some means for varying the size of—or completely closing off—these ventilating holes. Provision should also be made for the removal of the air after it has passed around the cylinders. Suction louvers in the rear engine cowling or individual troughs behind each cylinder will accomplish this purpose. Obstructions very close behind the cylinders should be avoided as they prevent the free flow of air

around the cylinders. In no case should the diameter of the cowling at the center line of the cylinders exceed 35 inches. The sketches at Figs. 772 and 773 show a type of engine cowl which incorporates the features described above and which has proven successful in various practical applications.

Fuel and Oil Lines.—It is a well known fact that the largest percentage of forced landings due to failure of the power unit is caused by failure of some part of the "plumbing" system The following recommendations are therefore considered of the utmost importance.

1. All lines should be made of soft seamless hot drawn copper tubing of the finest quality.
2. The entire tube should be annealed both before and after bending. If the bend is unusually severe it is advisable to anneal the tube frequently during the operation.
3. Hose connections should be of the best quality. In a properly made connection the ends of the tubes are square and are brought close together inside the hose. The tubes should be provided with substantial beads about ¼ inch from the ends and all burrs should be carefully removed.
4. Hose clamps should be of the type which the airplane manufacturer believes to be the strongest and most reliable parts available.
5. Vibration is very often the cause of failure of a seemingly well assembled line. All lines should be well braced.
6. "Air locks" or "gas locks" are caused by the collection of air or fuel vapor in the high point of an improperly constructed line. Avoid high points except at the ends of the lines.
7. For service in cold weather it is essential that the oil lines be covered with asbestos lagging. This enables the engine to maintain a higher oil temperature and a higher rate of oil circulation.

Cyclone Lubrication System.—If possible, the oil tank should be located so the oil level is above the oil pump. This location will eliminate trouble in priming. The lines from the tank to the engine should be short with as few bends as possible. Copper pipe of one inch diameter, annealed after bending, and well braced throughout its length to eliminate vibration, is recommended. The oil inlet and outlet connections on the engine will be found on the left hand side of the rear section behind the mounting pads. They are fitted with nipples of the proper size, beaded for hose connections. The vent from the oil tank may be piped back into the engine crankcase with a ½ inch diameter pipe entering the crankcase rear section through a ⅜ inch pipe tap hole below and to the left of the generator pad. With the vent installed in this manner, it is possible to avoid spilling oil from the tank during stunt maneuvers.

The oil-pressure line should be of ⅜-inch copper tubing connecting the pressure gauge on the instrument board with the pressure outlet which is found at the rear and bottom of the rear section on the outside of the main strainer chamber. This tubing should be annealed after bending and braced at frequent intervals to eliminate vibration. Ordinarily, it will not be necessary to install an oil cooler on Cyclone engines as the heat given to the oil is very small and is easily dissipated from the oil lines and oil tank. Under

certain extreme conditions a cooler may be necessary, in which case it should be inserted in the discharge line from the engine. Installations provided with an oil cooler should also include a relief valve and bypass to relieve the pressure in the cooler when starting in cold weather.

Fuel System of Cyclone Engine.—As the Standard Army-Navy fuel pump mount and drive are provided in the Cyclone engine, there are several fuel pumps which can be attached without change. If no fuel pump is supplied, the carburetor should be connected to a gravity tank by a ⅜-inch line of copper tubing which has been annealed after bending. This tank should have at least a twenty-inch head when the plane is inclined at the angle of its steepest climb. When a fuel pump is used the pump discharge should be connected to the carburetor and the discharge from the relief valve should be piped back to either the main fuel supply line or to the gravity tank. If a pressure-relief valve is not provided with the pump used, this part must be supplied as a separate unit in the main gasoline feed line, between the pump and the carburetor.

The fuel lines should be as simple as possible and free from vertical bends in which air pockets can form. The lines should be of soft copper tubing of at least a ⅜-inch inside diameter. The location of the throttle lever and the mixture-control lever are given on the installation drawing at Fig. 787. Both levers are ¼-inch thick and are drilled to take a ¼-inch clevis pin.

The priming pump should be located near the hand crank with the end of the plunger extending through the cowling where it will be easily accessible. There should be a shut-off valve in the line near the primer and this should be provided with a right angled handle which in the "off" position will extend across the primer handle. This indicates in a clear and forceful manner whether the valve is on or off. The primer fuel supply is drawn from the main fuel line through the reducing tee supplied and the primer discharge is connected to the supercharger diffuser chamber at the base of the No. 1 cylinder intake pipe. All lines are of ⅛-inch brass or copper tubing. Leakage through the primer is apt to flood the lower cylinders with raw gasoline and result in serious damage to the engine. The danger of primer leakage can be minimized by the installation and use of the valve described.

Carburetor Air Heater.—The carburetor air heater is attached to the carburetor with the air-inlet openings facing toward the rear. The exhaust connection should be attached to the exhaust port of the No. 5 cylinder. When these connections are installed, it is essential that the flexible tubing should be twisted up until tight in order to avoid leaks which may eventually result in burned out tubing. In assembling on the engine, clamp one end of each tube and turn on the other end in a counter-clockwise direction until the tube is coiled up tight. Then tighten up the second clamp. It is possible to interconnect the throttle and the heater controls in such a way as to provide heat at part throttle and atmospheric temperature at full throttle. This connection may lead to considerable complication, however, and is not recommended. The heater should be controlled by a separate lever in the pilot's cockpit. An adjustment is rarely necessary and is easily accomplished by manipulating the separate lever.

Magneto Wiring.—The top connections "P" of the magnetos should be connected with insulated ignition wire, to the points on the grounding switch marked "R Mag." and "L Mag." The point marked "Grd" on the switch should be connected to the engine crankcase. These wires should all be clipped at suitable points to prevent them from chafing on the engine or engine mount. This precaution is most important, as the proper functioning of the engine depends on the contacts made through these wires. On these contacts is also dependent the safety of the ground force working about the engine in the belief that the magnetos are truly grounded when

Fig. 788.—Installation of Wright "Cyclone" R-1750 Engine in Navy XPN12 Flying Boat, which Mounts Two of the Engines Between the Wings, One Each Side of the Hull.

the switch is in the "off" position. If an inertia or electric starter is used, a booster magneto is not essential; but it may be of considerable aid in cold weather. The booster magneto can be mounted in the cockpit, in which case the high-tension lead should be connected to the terminal "H" on the top of either magneto. The ground wire from the booster magneto should be connected to the terminal marked "Start" on the switch. If the booster is used from the ground, the high-tension lead should be inserted in the terminal marked "H" on one of the running magnetos and the body of the booster magneto should be grounded on the engine. In this case, the connection can be pulled out as soon as the engine starts and the magneto kept on the ground.

Miscellaneous Connections.—The spark-advance levers on the magneto are connected by rods, ball joints, and levers to a cross shaft running through the rear part of the crankcase. The right-hand end of this shaft

is provided with a lever to which the control rod is to be attached. The movement of this lever is 56 degrees, the radius is 1 7/16 inches, and the hole in the end is drilled for a 3/16-inch pin.

The two tachometer-drive connections will be found on the oil pump cover on the left-hand side of the rear section. These are of the U. S. Air Corps standard form with 7/8 inch-18 thread. They rotate at 1/2 crankshaft speed and, as viewed from the open end, in a counter-clockwise direction.

Any one of several types of starters can be supplied with Cyclone engines, as desired by the customer. On all starters a hand crank is required which fits over a shaft and drives through a pin. In most cases, the hand crank is supplied with the starter, but it may be necessary to change its length to suit various installations. An outside bearing in line with the starter shaft will be necessary. This bearing should be rigid and have sufficient clearance to allow for a slight misalignment of the hand crank and starter shaft. With the inertia starters, a push-pull control is necessary to operate the engaging dog. This control can be led to the pilot's seat or brought out near the crank. When the engine fails to start, it is sometimes necessary to push the control in order to disengage the clutch. To do this, a rod mechanism is essential. The same installation is required with the worm type of starter.

The propeller blade angles should be set to allow the engine to turn at approximately rated speed at full throttle, when the ship is in level flight. Other speeds are undesirable for several reasons. Low speed holds down the power of the engine, causes excessive torque vibration, and increases the tendency to detonate. High speed subjects the engine to strains which will shorten its life. The installation of a Standard Steel propeller is shown at Fig. 788, this being a three blade type fitted to a Cyclone engine. The engine mounting shown is that used in the Navy XPN12 flying boat. A more complete consideration of propeller installation will be found in the following chapter.

QUESTIONS FOR REVIEW

1. Name types of air-cooled engine mountings.
2. Which is easier, nose or wing installation and why?
3. What are principal requirements of engine mount?
4. How is exhaust gas disposed of?
5. Describe methods of cowling air-cooled engines.
6. What is the N.A.C.A. cowling and what are its advantages?
7. Outline steps in uncrating Wright J5 engine.
8. What should be done preliminary to starting J5 engine?
9. Detail method of starting J5 engine.
10. What is the ground test of the engine?

CHAPTER XLII

INSTRUMENTS—PROPELLERS—REDUCTION GEARS—ENGINE STARTERS

Aircraft Instruments—Engine Instruments—Airplane Control Aids—Airplane Navigation Aids—Special Airship Instruments—What Airplane Instruments Do—Typical Instrument Boards—Airplane Propulsion Methods—Cycloidal Propulsion—Propeller Development—Propeller Definitions—New British Variable Pitch Propeller—Screw Overlap in Multi-Engine Types—Monoid Propellers—Propeller Hubs—Fitting New Hub to Shaft—Design and Construction of Metal Propellers—Reed Metal Propellers—Manufacture and Tests of Reed Propellers—Standard Steel Propellers—Propellers More Efficient at Low Speeds—Airplane Propeller Drive Gears—Rolls-Royce Gear—Lorraine Planetary Gear—Self-starters for Aviation Engines—Engine Starting Methods—U. S. Navy Practice—Electric Starters—The Wright Hand Starter—Eclipse Aviation Engine Starters—BMW Hand Starting Gear—The Fiat Air Starter—Early Air Starting System—The Heywood Injection Air Starter—Eclipse Hand and Electric Inertia Starter Series VII—Eclipse Electric Starter-12 Volt—The Bristol Gas Starter—Eclipse Series 6 Starter—Operation of Eclipse Series 6 Starter—Maintenance—Clutch Setting—Determination of Clutch Value.

Aircraft Instruments.—An airplane or airship, has a wide variety of instruments, some of which are merely modifications of devices previously used on automobiles and ships and a number that have been devised especially to meet the peculiar operating conditions found only in aircraft. For example, the tachometer that records the engine speed is a modification of the automobile speedometer, oil and pressure gauges are similar to like instruments in automobiles. The magnetic compass is a modified form of ship's compass. Then we have that class of special instruments such as Bank and Turn indicators, earth induction compass, rate of climb indicator and air speed indicator that have been developed only for aircraft use.

It is not possible, in a book of this general character to devote the space that would be necessary to describe completely the instruments, recorders and other devices that have been developed and found necessary in the operation and maintenance of military and commercial aircraft as a proper and adequate consideration of this subject demands a volume of its own. The design and correct application of instruments is work on which a person might specialize for a lifetime without exhausting its possibilities. The reader is referred to the treatise *Modern Aircraft*, a companion volume to this one and issued by the same publishers for a complete outline of aircraft instruments. Instruments, in the opinion of the writer may be classified as follows:

(a) Engine Instruments: Switch, Ammeter (Battery System), Tachometer, Thermometers, Fuel and Oil Level Gauges, Fuel and Oil Consumption Gauges, Engine Gauges, Air Pressure and Oil Pressure Gauges, Supercharger Indicators.

(b) Airplane Control Aids: Bank and Turn Indicator, Rate of Climb Indicator, Pitching Indicator, Air Speed Indicators, Altimeters, Anti-Stall Devices, Gyroscopic Control.

(c) Airplane Navigation Aids: Altimeter, Magnetic Compass, Earth Induction Compass, Goerz Sun Compass, Sextants, Clock, Air Distance Recorder, Drift Indicator, Radio Directional Compass.

(d) Special Airship Instruments: Manometers, Gas Pressure Alarm, Gas Leak Indicators, Gas Temperature Indicators, Statoscopes.

From the foregoing it will be evident that no attempt has been made to classify instruments having to do with military activities or radio communications. A fully equipped military airplane for reconnaissance or bombing is really a flying laboratory and arsenal because in addition to the

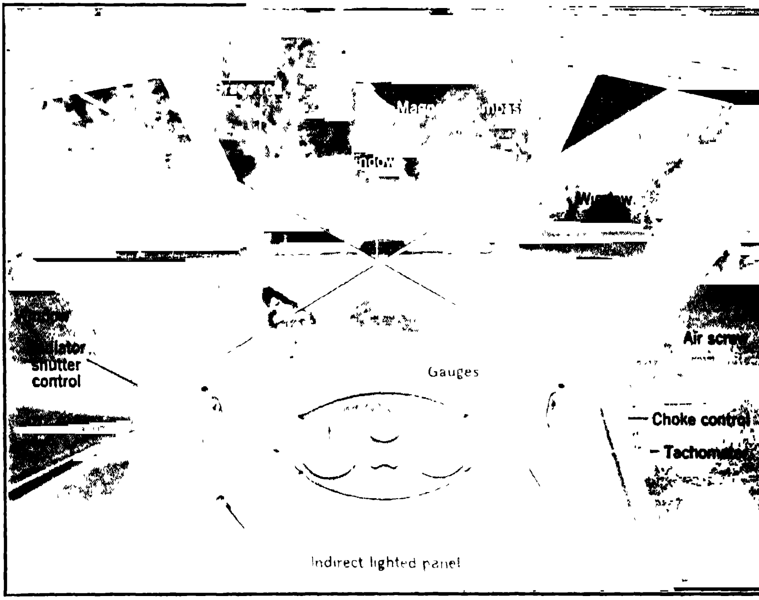


Fig. 789.—View from Pilot's Seat in the Curtiss Robin Cabin Monoplane, Showing Excellent Vision and Neat Instrument Board Installation.

instruments enumerated it carries armament, radio, camera, bomb dropping and sighting apparatus and other items not used in commercial aircraft for general applications. If operated at high altitudes, oxygen regulating and supply devices are necessary.

The number of instruments used varies with the type of airplane. Some of the smaller commercial types of airplanes have obtained good results with a few good instruments. The illustration at Fig. 789 is a view from the pilot's seat of the Curtiss Robin cabin plane and shows the excellent vision afforded the pilot as well as the neat instrument board installation. In addition to the indirect lighted panel made by the Consolidated Instrument Company of America, Inc., which groups an oil pressure gauge, a thermometer, tachometer and altimeter; a magnetic compass is mounted

above the front window and an air speed indicator is placed above the panel. At each side of the panel, levers to control the choke and radiator shutters are placed. Below the panel at the right is a handle controlling the gasoline feed while the magneto switch is placed at the left. An enlarged view of the indirect lighted instrument panel, which is used by a large number of commercial airplane manufacturers is shown at Fig. 790. The instruments used on a "sport" plane are few in number as shown at Fig. 790 A. The instrument board of the Keystone Pathfinder is shown at Fig. 790 B and is considerably more complete than the equipment of a small ship.

The airplane is different from the motor car in that it is operated for the most part at the present time on uncharted airways whenever it departs from the few established airways that have been lighted and charted by the United States Air Mail or Army Air Service or that have been established by the Department of Commerce. For this reason large aircraft

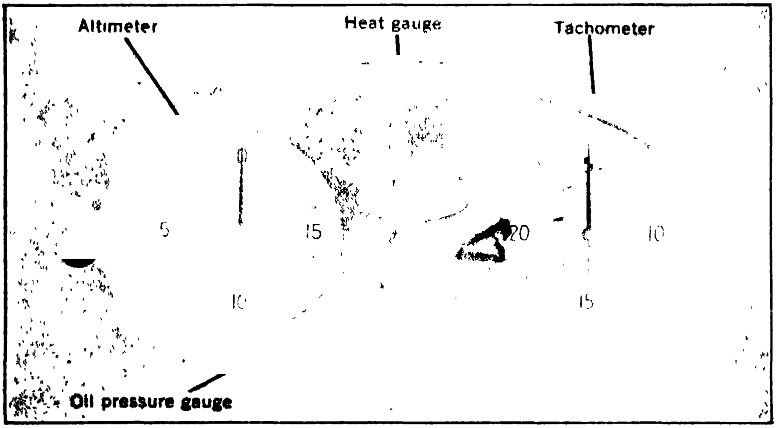


Fig. 790.—Consolidated Indirect Lighted Panel, Type A Groups Altimeter, Tachometer and Temperature and Oil Pressure Gauges for Neat and Easy Installation.

making long trips must have all of the instruments that are needed in Marine Navigation. As so much depends on the engine, or engines, as the case may be, the airplane pilot must have a series of indicating instruments that will show how the powerplant and its auxiliaries are functioning and all airplanes, even the smallest, should have at least a tachometer, thermometer and oil pressure gauge. A ship is navigated, when out of sight of landmarks by compass and sextant observations, but in addition to these, the navigator of an aircraft must also have instruments showing his direction and speed of travel vertically as well as horizontally. The pilot may be operating his airplane in a heavy fog, or in the clouds where he can not always place reliance upon his senses so various instruments must be provided by which he can be aided in controlling his airplane. The instruments used by Lindbergh on his New York to Paris flight are shown at Fig. 791.

What Airplane Instruments Do.—The air speed indicator corresponds to the speedometer of an automobile and gives an indication of the speed

the airplane is making, which taken in conjunction with the clock will make it possible to determine the distance covered at a flight. The altimeter, which is an aneroid barometer, outlines with fair accuracy the height above the ground at which a plane is flying. These instruments are furnished to enable the aviator to navigate the airplane when in the air, and if the machine is to be used for cross-country flying, they must be supplemented by a compass and a drift set. It will be evident that these are purely navigating instruments and only indicate the motor condition in an indirect manner. The best way of keeping track of the motor action is to watch the tachometer or revolution counter which is driven from the engine by a flexible shaft. This indicates directly the number of revolutions the engine is making per minute and, of course, any slowing up of the engine in normal flights indicates that something is not functioning as it should.

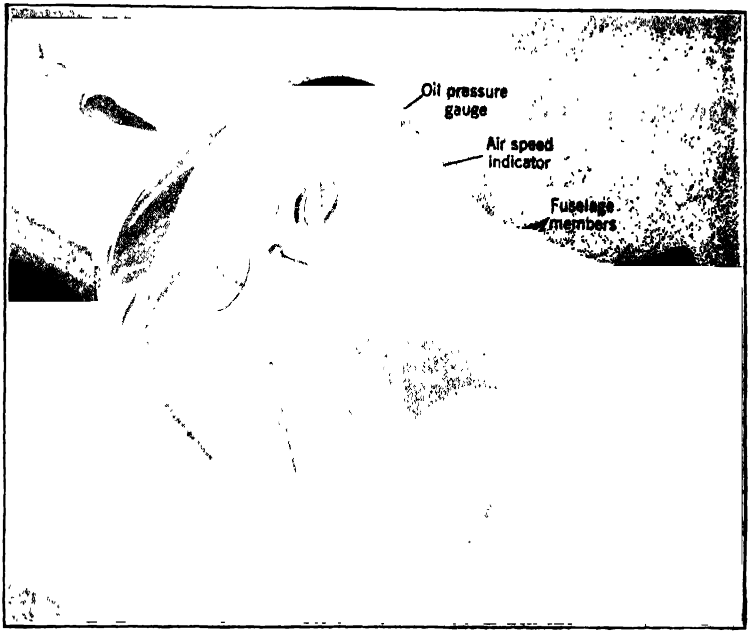


Fig. 790A.—Instruments Used on Light Driggs Dart Sport Plane Include Those Absolutely Necessary for Flight.

The tachometer operates on the same principle as the speed indicating device or speedometer used in automobiles except that the dial is calibrated to show revolutions per minute instead of miles per hour. At a point convenient to the pilot the spark advance and throttle control levers are placed. These, of course, regulate the motor speed just as they do in an automobile, and a typical installation is shown in the early part of the chapter at Fig. 764, where they are mounted on the side of the fuselage adjacent to the pilot's seat. In dual control double cockpit machines, two sets of instruments and engine controls are usually installed, though on large air liners

where the regular and relief pilots sit side by side, one set of instruments will suffice and the motor control levers are usually placed between but forward of the seats so they can be manipulated by either pilot.

Typical Instrument Boards.—The instrument boards shown at Fig. 792 are those of Fokker Universal monoplanes used by the Colonial Airways, Inc., these having practically the same instruments. The upper panel has magneto switch, tachometer, thermometer, oil pressure gauge, air speed indicator, turn and bank indicator, earth inductor compass indicator, altimeter, clock, compass controller, landing light switches, navigation light

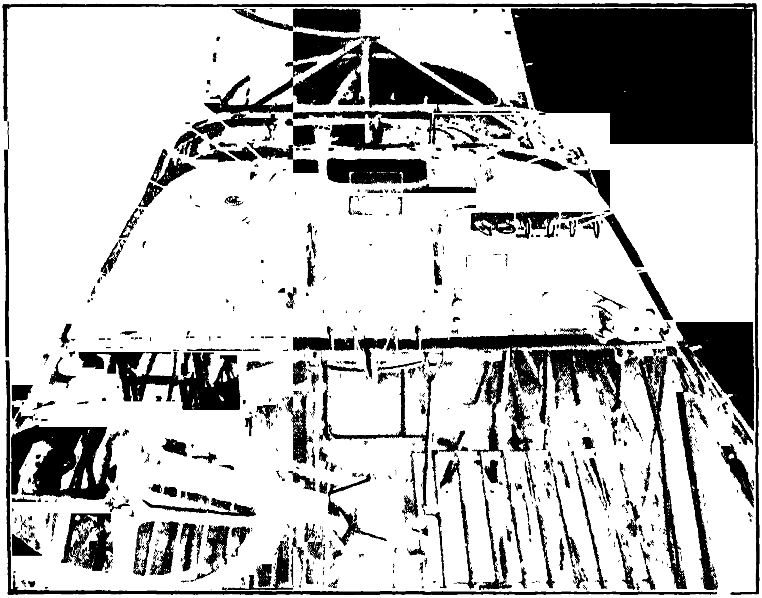


Fig. 790B.—Instruments and Control of Keystone Patrician Bi Motor Air Liner.

switch and lights and rheostat for same. The panel shown below it has a different type of tachometer incorporating recording and indicating mechanism. In addition to the instruments shown on the upper panel, the lower one carries a flare testing and firing unit and a primer to facilitate engine starting. Combination instruments have been devised in which the various engine temperature and pressure recording gauges are combined in one panel to facilitate installation. This type of gauge replaces three separate round dial instruments and occupies a minimum of instrument board area. With a vertical dial tachometer this instrument forms a complete powerplant unit. The engine gauge is shown at Fig. 793 A and the internal construction is shown in the side view at Fig. 794. Another useful instrument is the distance type fuel level indicator shown at Fig. 793 B. The cut at Fig. 793 C shows the installation of the fuel gauge.

The Pioneer Engine Gauge Unit is mounted in the instrument board in

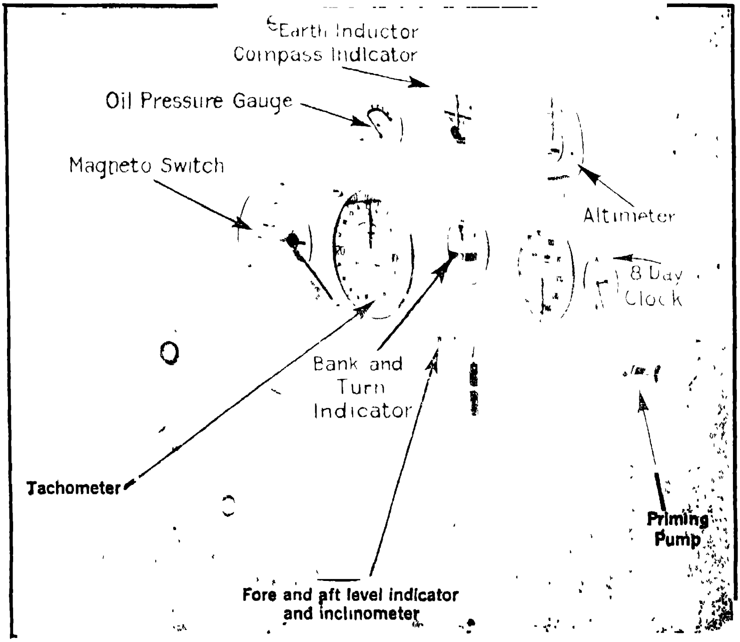


Fig. 791.—The Instrument Board of Lindbergh's Ryan Plane, "The Spirit of St. Louis," on His Epochal New York to Paris Flight.

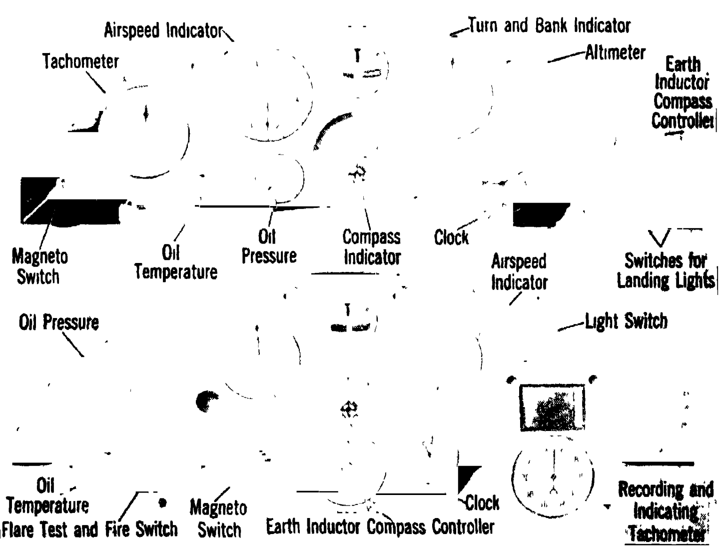


Fig. 792.—Instrument Boards Used on Fokker Universal Monoplanes Flown by Colonial Airways, Inc.

the same way as any other vertical scale instrument. Pressure elements are fitted with 7⁄16 inch by twenty thread male connections. Run the fuel and oil pressure tubes from the proper places on the fuel line and engine to the back of the gauge, avoiding sharp bends and fastening securely at short intervals to prevent vibration. Slip a union nut over each tube and solder connection nipples to the tube ends. Nuts and nipples are standard tube

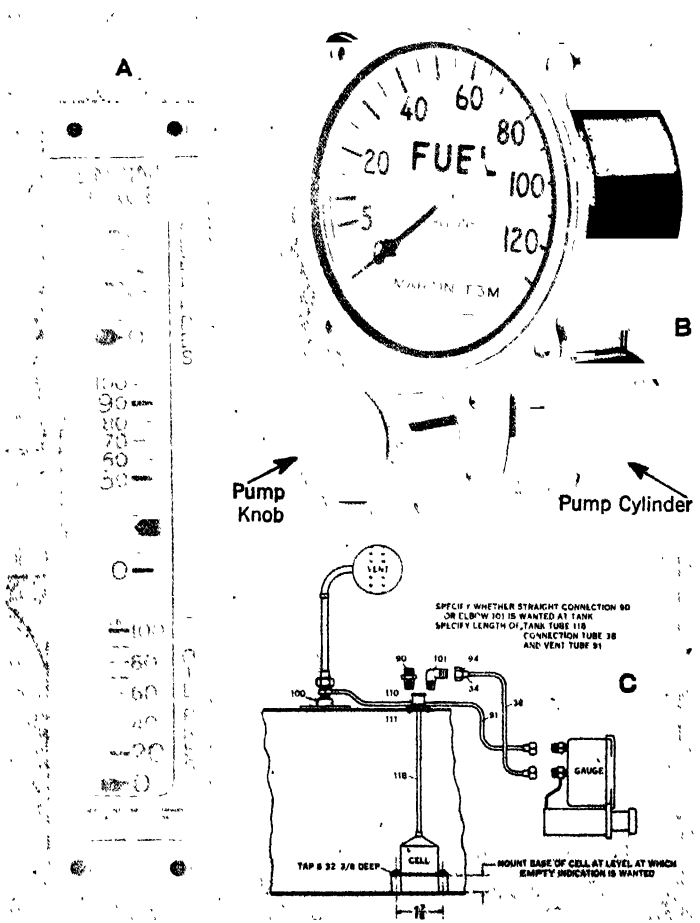


Fig. 793.—Pioneer Engine Gauge at A Combines Pressure and Temperature Indicators. B—Distance Type Fuel Level Indicator. C—How Fuel Indicator is Installed.

fittings and are not furnished with the Unit unless specially ordered. Clean and oil threads on the gauge connections. Tighten union nut until nipple seats properly to make a tight joint. Avoid excessive strain on the instrument. The bulb on the end of the thermometer tubing is fastened in the radiator or at any other point in the water or oil system where it is desired

to measure the temperature. The bulb is held in place by a clamp nut ⅝ inch diameter by eighteen threads per inch which is screwed into a similarly tapped hole. Extreme care should be taken in handling the thermometer bulb and tubing. Be careful not to dent the thermometer bulb or bend the thermometer tubing too sharply. If the tube is too long, it may be coiled without affecting the accuracy of the instrument, but the coil must be carefully secured to prevent vibration from loosening the joints at the bulb or at the instrument.

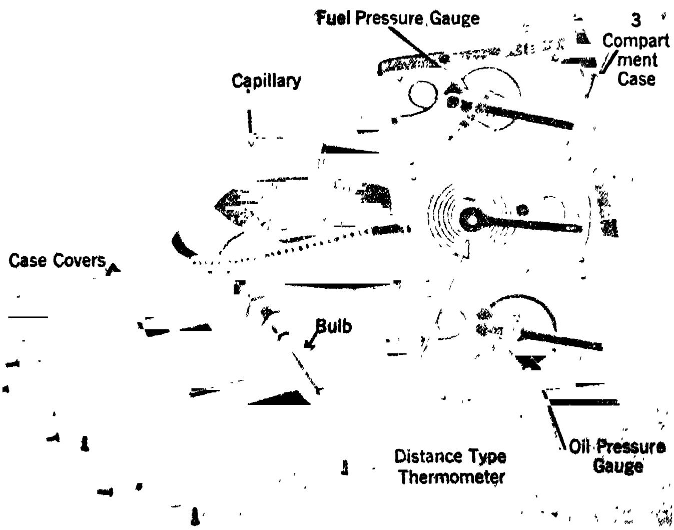


Fig. 794.—Side View of Pioneer Engine Gauge with Covers Removed to Show Method of Combining Pressure and Temperature Indicating Instruments for Compact Installation.

Airplane Propulsion Methods.—There are a number of ways proposed to obtain power in the form of thrust for aircraft propulsion, that commonly used being an adaptation of the screw propeller so generally utilized for ship propulsion, the length of the blades and their width being much greater than marine screws to compensate for the lessened density of the medium in which the airplane propeller must work. The characteristics of the engines used as well as the proportions of the aircraft and speeds they are to attain determine the diameter and pitch of the propeller. The reader who is not familiar with propeller nomenclature or action is referred to a very comprehensive chapter on the elementary theory of the screw propeller in *Modern Aircraft*, which is a companion volume to this treatise and issued by the same publishers.

Reaction propulsion by means of rockets has been experimented with in Germany, this system doing away with engines altogether and in its theoretical conception promising great speed even in rarer atmosphere where the screw propeller could not be used at all. The idea of exploding charges of combustible element, such as gas or gun powder in a cylinder

and depending upon the pressure of the issuing gas stream to push a plane through the air is not a new one. Practical consideration shows that there are many factors to be overcome before rocket or reaction propulsion can become a reality in aircraft though experiments made with automobiles have shown that great energy is liberated by rockets and that the reaction is able to propel racing cars at high speed.

The success that glider enthusiasts have had with their light, motorless craft has caused other inventors to envision trains of aircraft in which a towing airplane would pull numerous glider types through the air just as a locomotive now pulls a train of cars. Of course, there are many practical difficulties of controlling such a train that become apparent upon consideration. It is not likely that the screw propeller will be superseded by other means for a long time to come, and no better method of transforming the turning effort or torque developed at the crankshaft of the engine to the push or pull required to move aircraft through the air has been proposed that seems capable of such direct and simple application as the aerial screw. Various arrangements of paddle wheels and wings which are to give combined supporting and propulsive thrusts have been patented by optimistic inventors to move dirigibles and planes through the air and even rapidly vibrating membranes and large pulsating diaphragms actuated by the engine have been proposed by others. Other systems call for mounting one or more turbine type air blowers at the mouth of a long tunnel to draw in a stream of air and force it through the tube to the rear of the craft and then depend on the reaction of the issuing air stream to force the airship forward, but this can be considered the equivalent, mechanically, at least, of the air propeller, which is a blower of the fan type instead of the enclosed rotor or centrifugal "squirrel cage" type.

Cycloidal Propulsion.—A new method of aerial propulsion, applicable to both lighter-than-air and heavier-than-air machines, has been described by Frederick Kurt Kirsten, Professor of Aeronautical Engineering at the University of Washington, and was reported in *Automotive Industries.* It is known as cycloidal propulsion. As applied to a heavier-than-air machine it consists in the use of two propeller wheels, one on each side of the fuselage, at about the same points where the wings are usually located, these propeller wheels performing the functions of both the wings and the propeller of an ordinary airplane. Each propeller wheel has a number of blades, mounted on the spoked wheel in such a way that they can rotate around their own axis. By means of gearing, the propeller wheel is rotated around its axis, and each of the propeller wheel blades is rotated around its own axis at one-half the speed of wheel rotation. Thus, if the blade had a radial position when at the top of the wheel, it would have a tangential position when at the bottom of the wheel and in the top position it would produce a propelling effort while in the bottom position it would produce very little drag. As a matter of fact, the blade gearing is so adjusted that the blades come into the radial—the most effective—position shortly after having passed through the top position, so that both a propelling and a lifting effort is produced. These two components of the propeller force should, of course, be proportional to the drift and lift, respectively. A comprehensive test of cycloidal propulsion was conducted for the Bureau of Aeronautics of the U. S. Navy. It is hoped that the test report to the bureau

will be published in the near future by the Engineering Experiment Station of the University of Washington. As shown in diagram at Fig. 795, it will be apparent that such mechanism involves more moving parts and will weigh considerably more than the conventional propulsive medium so its practical application seems rather doubtful to the writer as even if its efficiency is high, the mechanical complication will prove a drawback.

Propeller Development.—This history of the development of the airplane propeller is soon told. In 1909 the propellers used by the Wright brothers were of wood with wide paddle-like tips. The thrust loads were probably less than 100 pounds on each blade. In 1910 the favorite propeller

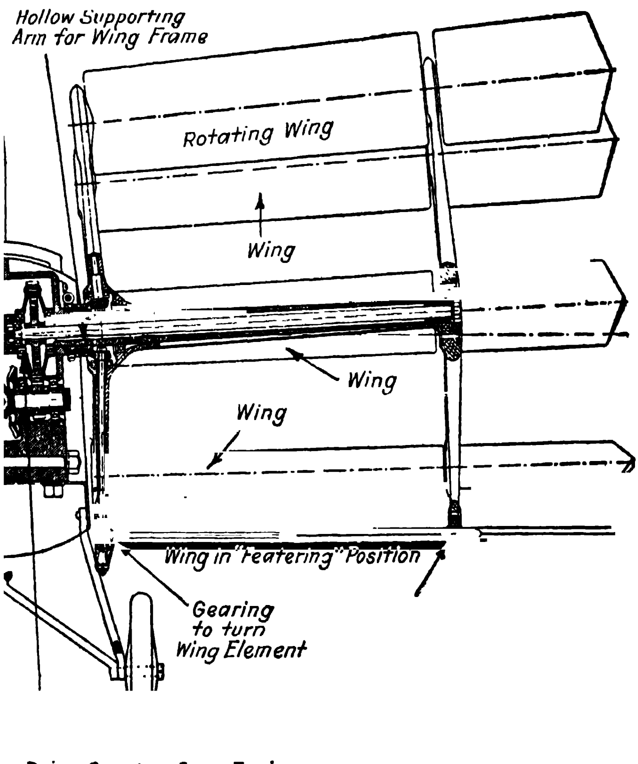


Fig. 795.—Cycloidal Propulsion Method Advanced for Aircraft is Unusual and Appears Complicated and Heavy.

abroad was that used on the Voisin and Antoinette made with two steel stems extending each way from the hub, to which stems sheets of metal were riveted so the blade was like a willow leaf. These metal sheets were concave on the driving faces. The loads on these blades were about 50 pounds. Farman also used a similar propeller in 1910. In 1912 we find

the laminated wood propeller coming in and entirely displacing all other types. No material change then occurred for ten years, even through the Great War, when the slightest improvement in performance would have been of value beyond estimate.

It is proper, however, to mention that in 1913 the Garuda wooden propeller came into notice and had a considerable effect upon design methods. This propeller had a forward rake of the blades, which by balancing against centrifugal force relieved the bending stresses at the blade roots and made it possible to reduce some of the bulk with safety. It was always realized that metal would be superior to wood, but except for experimental types no metal propellers came actually into service until 1922, when the Leittner-Watts hollow steel blade propeller began to be used in England, and in March, 1922, the U. S. Navy ordered six Reed duralumin propellers for Vought E7 Hispano service planes, and in 1923 the U. S. Army received for service

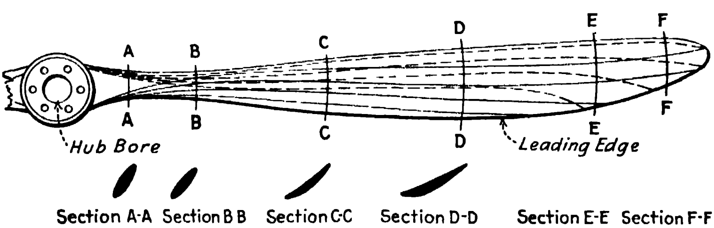


Fig. 796.—How Wooden Propeller Blade is Shaped at Various Stations Along Blade. Note Aerofoil Section at Different Points and Lessened Angle of Incidence as the Tip is Approached.

a number of detachable duralumin blade propellers. It was evident that an entirely novel type of propeller had appeared, viz., the thin solid blade of forged heat-treated aluminum alloy. This is now fully recognized by the aircraft world as the first substantial advance in propellers since 1912.

Propeller Definitions.—Before considering the constructional features of propellers used for the propulsion of aerial craft, it will be well to give some brief definitions. A right-hand propeller is one that when viewed from the rear, turns with the hands of a watch when driving the machine to which it is fitted ahead. Under similar circumstances a left-hand propeller turns against the hands of a watch to produce forward movement. If a right-hand propeller is turned toward the left, the effect will be to produce a reverse movement of the object to which it is applied. The "face" of a blade is the practically straight back surface, that which drives the fluid back while the screw is going ahead. The "back" of the blade is the side opposite the face, and care must be taken to avoid confusion of terms, from the fact that the "face" of a blade is aft and the "back" forward. The back of the blade is usually a cambered surface.

"The leading edge" of a blade is the edge which cuts the fluid first when the screw is turning ahead, while the "following edge" is opposite the leading edge. The "leading edge" is usually curved more than the "following edge." The "diameter" of a screw is the diameter of the circle described

by the tips of the blades. In symmetrical two- and four-bladed screws it is simply the distance from the "tip" or outermost part of one blade to that of the opposite member. The "pitch" at a given point of the face is the distance from the axis of the shaft which an elementary area of the face at the point, if attached by a rigid radius to the axis, would move during one revolution, if working in a solid fixed nut or nonresilient medium. The pitch may be different at every point of the face. If it is the same at all points we say that the pitch is "uniform." If the pitch is greater along the following than the leading edge, it is said that the pitch "increases axially," and if it grows greater as we leave the center we say the pitch "increases radially."

The "area" or "developed area" of a blade is the surface of its face, and the "blade area" of a screw, sometimes called its "helicoidal area," is the amount of face surface of all its blades. The "disc area" of a propeller is the area of a circle described by the tips of its blades. The "boss" of a screw is the cylindrical center to which the blades are attached, and the "hub" is the metal clamp by which it is attached to the revolving driving shaft. When a propeller is working with "slip" it advances during each revolution a distance less than the pitch, the difference between its actual advance and the pitch indicates the amount of slip. The "speed" of the screw is the distance it would advance in a unit of time, supposing it to be working in a solid nut. This is obviously equal to the pitch of the screw multiplied by the number of revolutions per unit of time. If the screw is held so that it can move only in a rotary direction as in the case when the propeller is turning but the airplane is held by "chock blocks" under the wheels, the column of fluid it sets in motion will only move. If the screw is operating in an immovable medium, the screw will move in a direction parallel to its longitudinal axis, as screwing a bolt into a piece of iron. If both screw and fluid are free to move, the degree of movement will depend upon the "slip" between the screw and the medium in which it works. For a more complete discussion on propellers, both elementary and practical, their care and methods of manufacture, the reader is referred to *Modern Aircraft,* a companion volume to this treatise and published by the same publishers.

Propellers are made in two-, three- and four-blade types, the former being the most popular. A two-blade is the most desirable as it is the easiest to build and balance and the most efficient at high speeds. In order to hold down or utilize the full power of a large engine, it is sometimes necessary to use a three- or four-blade type because a two-blade form, suitable to absorb the power, would need excessive pitch or diameter. Propeller blades have been made of natural materials as wood or metal and synthetic materials, such as Bakelite or Micarta. As shown at Fig. 796, the section of the blade varies at different points from the hub or boss to the tip, these sections usually having the same properties as aerofoil sections from which they are taken. The empirical rule that is followed usually in designing either wood or metal propellers having two blades for use in the air is as follows: The diameter should be as large as possible compatible with the limits of design; the blade area should be from ten to fifteen per cent that of the area swept; the pitch should be approximately four-fifths the diameter, and the speed of rotation should be moderate. As

PROPELLER PITCH SPEEDS
Given in Miles Per Hour and Revolutions Per Minute

Pitch in Feet	Revolutions Per Minute														
	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700
2'-0"								22.7	25.0	27.3	29.5	31.8	34.1	36.4	38.6
2'-6"							25.6	28.4	31.2	34.1	36.9	39.8	42.6	45.4	48.3
3'-0"						27.3	30.7	34.1	37.5	40.9	44.3	47.7	51.1	54.5	57.9
3'-6"					27.8	31.8	35.8	39.8	43.7	47.7	51.7	55.7	59.7	63.6	67.6
4'-0"				27.8	31.8	36.4	40.9	45.4	50.0	54.5	59.1	63.6	68.2	72.7	77.3
4'-6"			25.6	30.7	35.8	40.9	46.0	51.1	56.2	61.4	66.5	71.6	76.7	81.8	86.9
5'-0"		22.7	28.4	34.1	39.8	45.4	51.1	56.9	62.5	68.7	73.9	79.5	85.2	90.9	96.6
5'-6"	18.4	25.0	31.2	37.5	43.7	50.0	56.2	62.5	68.7	75.0	81.2	87.5	93.7	100.0	106.2
6'-0"	20.5	27.3	34.1	40.9	47.7	54.5	61.4	68.7	75.0	81.8	88.6	95.4	102.3	109.1	115.9
6'-6"	22.2	29.5	36.9	44.3	51.7	59.7	66.5	73.9	81.2	88.6	96.0	103.4	110.8	118.2	125.6
7'-0"	23.9	31.8	39.8	47.7	55.7	63.6	71.6	79.5	87.5	95.4	103.4	111.3	119.3	127.3	135.2
7'-6"	25.6	34.1	42.6	51.1	59.7	68.2	76.7	85.2	93.7	102.3	110.8	119.3	127.3	136.4	144.9
8'-0"	27.3	36.4	45.4	54.5	63.6	72.7	81.8	90.9	100.0	109.1	118.2	127.3	136.4	145.4	154.5
8'-6"	29.0	38.6	48.3	57.9	67.6	77.3	86.9	96.6	106.2	115.9	125.6	135.2	144.9	154.5	164.2
9'-0"	30.7	40.9	51.1	61.4	71.6	81.8	92.0	102.3	112.5	122.7	132.9	143.2	153.4	163.7	173.8
9'-6"	32.4	43.2	54.0	64.8	75.6	86.4	97.2	107.9	118.7	129.5	140.3	151.1	161.9	172.7	183.4
10'-0"	34.1	45.4	56.8	68.2	79.5	90.9	102.3	113.6	125.0	136.4	147.7	159.1	170.5	181.9	193.3

Table by Rathbun Showing Propeller Pitch Speeds in Miles Per Hour and R.P.M.

the speed of rotation is increased, the diameter must be reduced. Maximum thrust effort will be obtained with large diameter and low speed. Airplane propellers were formerly invariably made of wood because this material is the one that has the greatest strength in proportion to its weight and has been found to be the best adapted when constant changes are necessary as in experimental work. Commonly used woods in American manufacturing practice are Honduras mahogany, birch and white oak. Spruce, maple, cherry, ash and poplar are sometimes used. English practice favors mahogany and black walnut. A laminated blank has much greater strength than a solid piece would have owing to the method of so arranging the wood laminations that the grain of one crosses that of neighboring ones and also because woods of different weight and strength can be used in the same propeller. These layers are glued together under pressure to form a

SPEED AND THRUST OF TWO BLADE PROPELLERS

Diam.	Pitch	R.P.M.	Thrust	Diam.	Pitch	R.P.M.	Thrust
7'-6"	5'-3"	1000	320	8'-6"	5'-6"	1000	460
7'-6"	5'-3"	1100	380	8'-6"	5'-6"	1100	520
7'-6"	5'-3"	1200	440	8'-6"	5'-6"	1200	580
7'-6"	5'-6"	1300	500	8'-6"	5'-6"	1300	640
7'-6"	5'-3"	1400	560	8'-6"	5'-6"	1400	700
8'-0"	5'-3"	1000	400	9'-0"	6'-0"	1000	520
8'-0"	5'-3"	1100	460	9'-0"	6'-0"	1100	580
8'-0"	5'-3"	1200	520	9'-0"	6'-0"	1200	640
8'-0"	5'-3"	1300	580	9'-0"	6'-0"	1300	700
8'-0"	5'-3"	1400	640	9'-0"	6'-0"	1400	760
8'-0"	6'-3"	1000	476	9'-6"	6'-0"	1000	650
8'-0"	6'-3"	1100	552	9'-6"	6'-0"	1100	750
8'-0"	6'-3"	1200	628	9'-6"	6'-0"	1200	850
8'-0"	6'-3"	1300	704	9'-6"	6'-0"	1300	950
8'-0"	6'-3"	1400	780	9'-6"	6'-0"	1400	1050

Table by Rathbun Showing Speed and Thrust of Some Typical Two Blade Propellers.

blank which is afterwards fashioned by hand tools or machinery to form the finished member.

The fixed blade propeller is the form, either of wood or metal, in which the blades always bear a fixed angular relation to the boss and are permanently attached to it. The pitch of such a propeller, unless warped or changed by accidental causes, always remains at the point determined when it was manufactured. The usual wood propeller or a Curtiss-Reed dural screw are "fixed" blade types. The adjustable pitch propeller is one in which the blades are manufactured separately from the boss or hub and are secured to it by such mechanical means as will permit the angle being changed by changing the relations of the blade to the hub. Some new metal screws such as the Standard Steel and Westinghouse Micarta blade propellers have been devised following this construction which is a great advantage in experimental work.

All adjustable blade propellers are variable pitch propellers but this term is usually applied to those types in which blade position may be changed by mechanical means while the aircraft is in flight, whereas the ordinary "adjustable" blade is not disturbed except for replacement or repair once the best setting has been found "Variable pitch" propellers may be changed while the screw is under power by suitable mechanism operated by the pilot, "adjustable" blade propellers must be stopped to alter blade position and such adjustments can only be made with the plane on the ground.

A propeller having a variable pitch controlled by the pilot while in flight has the advantage of permitting thrust and resistance to be closely matched. For example, in altitude flying, the air is less dense and a greater pitch would be needed than when near the ground. They are heavier than fixed pitch blades and as they have considerable operating mechanism, this is apt to get out of order and it adds to the weight of the airplane. A reversible propeller is a form in which the position of the blades may be entirely reversed by internal mechanism so the engine direction of rotation need not be changed to secure a propulsive force or a tractive force. They have received some application in marine service but manufacturing difficulties prevent their practical application in aircraft though they have been used experimentally in both airplanes and dirigibles. In dirigible balloons reversible propellers would permit of better maneuvering and would make quicker turns possible as well as exerting a braking effort when landing, while in an airplane, it is believed that reversing the propeller would act as an air brake when landing, though what would happen if the control was inadvertently operated while the airplane was in flight is a matter of conjecture. Dirigible balloons can fly backward to a limited extent but an airplane is built to fly in only one direction and that is nose first.

New British Variable Pitch Propeller.—A new variable pitch propeller for airplanes was described in a paper presented to the Royal Aeronautical Society of Great Britain, the authors of the paper, Dr. H. S. Hele-Shaw and T. E. Beacham, being the inventors of the device. The propeller has been developed to a practical state by the Gloster Aircraft Co., and fitted to a number of different models of plane. The first design to be actually applied in practice was that for the Jupiter engine. The pitch of the blades in the propeller is varied by means of a double-acting hydraulic piston

operated by the oil pressure from a variable stroke pump driven by the engine. The stroke of the pumps is in turn controlled by a governor, also driven by the engine, so that whatever the air conditions may be, the pitch of the propeller sets itself so as to keep the engine running at a constant predetermined speed.

Although the apparatus is automatic, the speed at which the governor operates can be altered by the pilot within certain limits by means of a small control lever. In other words, the pilot has it within his power to speed up

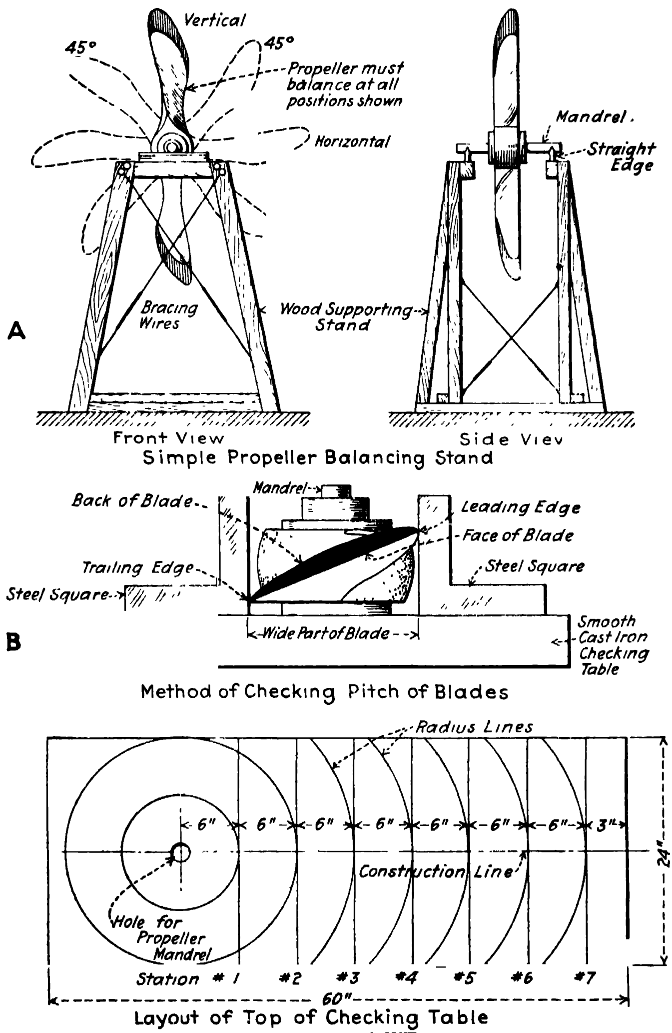


Fig. 796A.—How Propellers are Tested for Balance and Blades Checked for Pitch at Various Stations.

the engine and obtain extra power in an emergency, and also, on the other hand, to reduce his engine speed so that he may cruise at full throttle, this, of course, being the condition for minimum fuel consumption per brake horsepower developed by the engine. The pilot control lever alters the force on the governor spring and consequently adjusts the speed at which the governor operates.

The principle of operation of the variable pitch propeller is identical with that of the hydraulic steering gear with the addition that the control is automatic. An important matter insisted upon by the Air Ministry is provision for any possible failure of the hydraulic system, for instance, if in a war machine the pipes were shot away. It is claimed that this condition is satisfactorily met in the particular propeller referred to, together with the other two vital conditions of light weight and reliability. It may be added that one of these propellers has been 30 hours in flight at Farnborough—where it is being tested by the Air Ministry officials—without any suggestion of a breakdown.

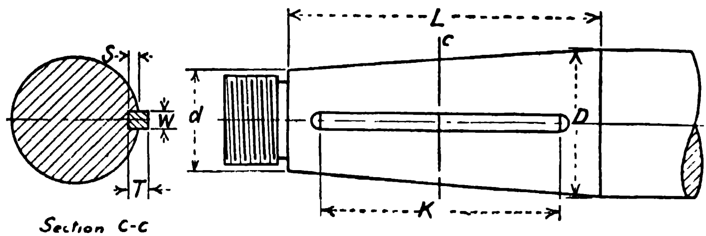
In the discussion of the paper (as reported in *The Engineer*) several speakers raised objection to the great weight of the variable pitch propeller but the authors made the statement that this would be reduced in later designs. Mr. Lynam, who is in charge of the Propeller Section of the Royal Aircraft Establishment, said that a great deal of the gloss was taken off the variable pitch propeller proposition by the weight. In many cases that annuled the advantages to be gained, and despite the success of the Gloster Hele-Shaw-Beacham propeller, he was not yet convinced that a very strong case could be made out for the variable pitch propeller, in general, for heavier-than-air craft. A good case, however, could be presented for this type of propeller on the airship. It appeared that the variable pitch propeller stood the best chance on geared engines when propellers of large pitch and diameter ratio and large surface were used. Mr. Lynam's remarks may be summarized by saying that unless by using a variable pitch propeller—and taking the weight of the propeller into account—we can obtain more power from the engine, and unless the additional power is gained at the rate of, say, one horsepower for two pounds weight, we should do better by putting that weight into the engine and using a fixed propeller.

One of the things necessary, he said, was a metal for the blades very much lighter than was available today. The Gloster propeller for the "Jupiter" engine weighed about 180 pounds as against 100 pounds for a fixed propeller of the same size with substantially the same blades—solid duralumin. An increase of 80 per cent in the weight was caused by the introduction of the mechanism for varying the pitch of the blades. He did not believe any form of solid construction would ever give light enough blades; hollow construction would have to be adopted, at any rate, for such large engines as the "Jupiter." Another means advanced for reducing weight was to depart from the practice of attaching the blade rigidly to the center. If the blade was hinged to the center, it became very much lighter. The hinge method was important and in fact absolutely necessary on aircraft of the La Cierva type, where the supporting element is really a four-blade propeller of very large diameter, but some difficulties will be present with high speed air screws as stops must be provided to limit the

movement of the blades if they are not rigidly attached to the hub and any form of hinge joint is introduced.

Screw Overlap in Multi-Engine Types.—In designing multi-engine planes especially if metal propellers are used, care must be taken so the propellers will not overlap. For example, in a trimotor plane with one engine mounted on the fuselage and two carried outboard; one under each wing, the outboard motors should be so spaced that the disc area, or blade swept area of their screws should be clear of the slipstream resulting from the central propeller. If there is an overlap, there is an area of disturbed

TAPER SHAFTS



Shaft No.	*L* Length	Included Angle[1]	*d* Diameter at Small End	*D* Diameter at Large End	Key			
					K Length	*W* Width	*T* Thickness	*S*
1	$5\frac{5}{32}$	5°43′30″ 1 2 in. per ft.	1 535	2.05	3	0.375+0.0000 −0 0005	0.2775±0.0005	0.156±0.002
2	7	5°43′30″ 1.2 in. per ft.	1 662	2 362	$5\frac{7}{16}$	0.473±0.001	0.236+0.001 −0.002	0.148±0.005

[1] The taper should vary from absolute uniformity by being from 0 000 to 0.001 in. larger at the large end.

Fig. 797.—S.A.E. Standard Dimensions for Taper End of Aero Engine Shafts.

air in which each blade of a side propeller will move during each revolution. The air pressure will vary and consequently the variation in thrust from the undisturbed air to that of the central propeller slipstream cannot fail to produce vibratory stresses in the blades. If wood propellers are used, much of this vibration will be absorbed by the material of which the blade is composed. If metal blades are used, the stress will be transmitted along down the blade to the point of attachment at the hub. If this is weakened by holes, there may be a very slight movement, that repeated 3,000 times per minute, will in time fatigue the stressed metal. Metal propeller failures have always taken place at the point where the greatest stress was not adequately resisted, or in the center portion.

When two engines are mounted tandem, the disc area of the rear propeller should be such that it will lie entirely within the slipstream of the front propeller. In such installations the tractor screw is sometimes of lesser pitch and greater diameter than the pusher screw, which must work in disturbed air. Overlapping is not common in twin-motored airplanes where each engine is carried outboard because the fuselage usually comes between the engines. In seaplanes, where the engines are carried above the boat hull there is also an appreciable space between the power units and the disc areas of the screws are separated by a corresponding space. The air screws of trimotored airplanes that may appear to have an overlap when viewed from the front may have no real overlap because the front engine may be located far enough forward so its slipstream will have necked down before the side propellers can intercept it. The amount of this diminution in slipstream area may be taken as 80 per cent of the diameter at a distance of 50 per cent of the diameter or more back of the propeller. The nature of the stresses set up in the after propellers of an overlapping combination are analogous to those set up in the after propeller of a tandem combination when in the latter case a sufficiently small diameter to prevent the tips from extending outside of the slipstream is not provided. It has been stated that this point has been taken into consideration in designing the latest Ford-Stout trimotored all metal monoplanes and other airplanes using three motors and that the wing supported motors are carried out far enough so there will be no contact of their blade tips with the slipstream of the central and forward screw.

Monoid Propellers.—The Monoid propeller was developed and perfected by Spencer Heath, whose name has been synonymous with airplane propeller development. Fully acquainted with the shortcomings of the old time lumber propellers Mr. Heath started more than three years ago experimenting with moulded, plywood propellers. In September, 1926, these were tried on ships under actual flying conditions. Since that time, Monoids, in the limited quantities that it was possible to produce before installation of special machinery and other equipment, have been used on planes of leading aircraft manufacturers. So successful have been the results with this new product and so widespread the interest and inquiries that the Paragon Engineers, Inc., are centering their manufacturing resources on the Monoid, alone. The Monoid is constructed from a large number of very thin layers of wood, principally birch, machine formed and tapered in such a manner that when the entire number are assembled and impregnated with water-proof cement, under pressure, in a specially prepared mould, the resulting product is a completely formed propeller substantially without external carving of any kind. The tapered layers of wood are so laid that the direction of their fibers alternate at a considerable angle between adjacent layers, thus giving a cement impregnated, interlaced fiber construction, which besides holding its shape perfectly, under all conditions, is almost indestructible in the ordinary sense of that term. While accomplishing these results the weight, including metal sheathing on the leading edge of high nickel alloy, is from fifteen per cent to 30 per cent less than propellers of ordinary lumber construction.

Propeller Hubs.—The engine crankshaft ends of small and medium powered engines are usually tapered and the propeller hub to fit has a corresponding taper. The drive is taken by one or two substantial keys in the shaft end which fit corresponding keyways in the hub. The hub is forced on the taper by a compression nut and a nut lock is always provided. The suggested S. A. E. standard for taper shaft ends is shown at Fig. 797. In some engines of foreign design, the drive end of the shaft is flanged as shown at Fig. 798 and engages the propeller hub directly by means of short countersunk head driving bolts as shown. The hub is centered by a flanged shoulder which fits a corresponding annulus in the engine shaft flange. This method of propeller hub retention is considerably lighter than the other and more common system.

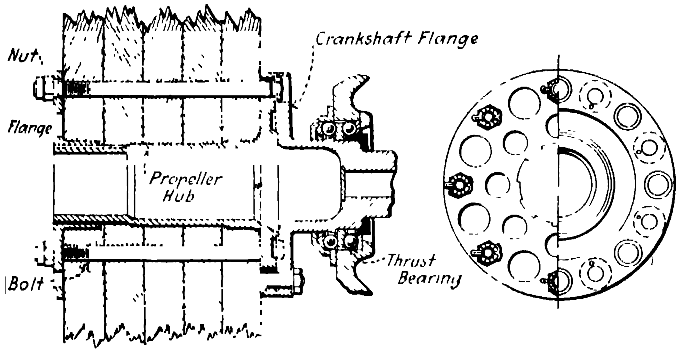


Fig. 798.—Propeller Hub of German Design is of Light but Strong Construction and Attaches to a Flange on Crankshaft.

Two practical and widely used forms of propeller hubs are shown at Fig. 799. That at A is the split hub used in connection with Standard Steel adjustable and removable blade propellers to be described. It is made to fit the standard splined shaft end and is centered by conical members. It is held in place by an externally threaded nut that fits the shaft end and is locked in place by a large split pin passing through the hub and the lock nut. The construction shown at Fig. 799 B is that used on Napier Lion engines. In this case the propeller lock nut is an internally threaded member and locked by a sheet metal stamping as shown. The lock nut has the centering cone integral and the movable flange is locked in place by a separate lock nut. The fixed flange, that forms part of the hub is the one nearest the crankcase. The inside of the hub is serrated or provided with long teeth or splines to mesh in the spaces between the splines on the engine crankshaft. The wooden propeller drive is by a series of eight substantial bolts that draw the hub flanges tightly against the propeller boss. In some cases, as in the propeller hub of the Fiat A20 and various other engines of both domestic and foreign manufacture, one of the propeller hub flanges is marked with timing index marks as shown at Fig. 800. In the hub shown, the drive is by interlocking splines in the hub and on the engine shaft. The fixed end of the propeller hub in the Fiat design is at

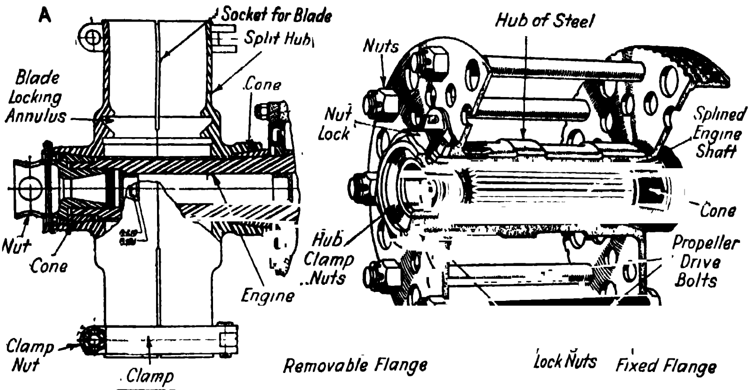


Fig. 799.—Propeller Hub Construction. A—Two-Piece Vertically Divided Hub for Standard Steel Two-Blade Propeller. B—Removable Flange Hub of Napier "Lion" Engine is Typical of Modern Practice When Wood Propellers are Used.

the front, whereas in most other applications it is at the end of the hub nearest the crankcase and the movable flange is at the front. The reverse mounting, as shown, means that the hub must be removed from the engine shaft to remove the propeller and this is good practice in any event because some believe the propeller assembly should always be balanced before use, if a new propeller is mounted on a hub to replace a damaged one. If the hub can be left mounted, the temptation is strong to just replace propellers

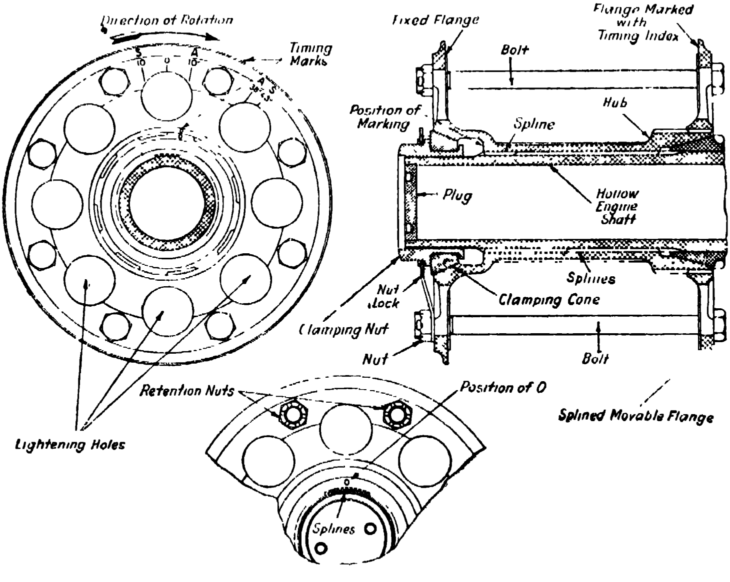
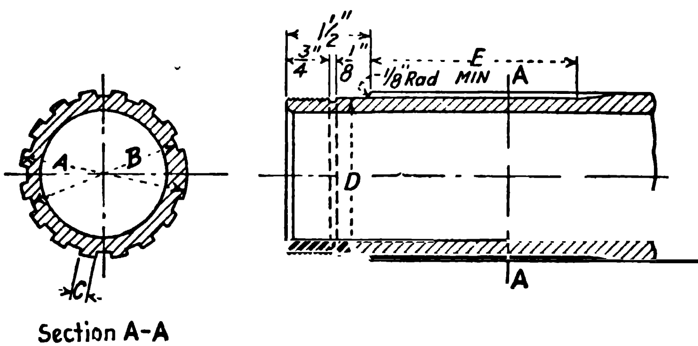


Fig. 800.—Propeller Hub Construction Used on Fiat Aero Engines is a Simple, Strong Type and Has Timing Index Marks on One of the Flanges.

by taking off a front mounted flange without balancing the assembly. The propeller hub is provided with the female seating of the centering cones and one of these cones is mounted on and screwed in with the internally threaded locking nut. A sheet steel nut lock is provided to prevent loosening of the assembly. The markings for timing make it imperative that the propeller hub be replaced on the engine shaft always in the same position it occupied before removal. The marking O must be matched up, both on the engine shaft, the hub and its removable flange.

S. A. E. Standard

SPLINED SHAFTS

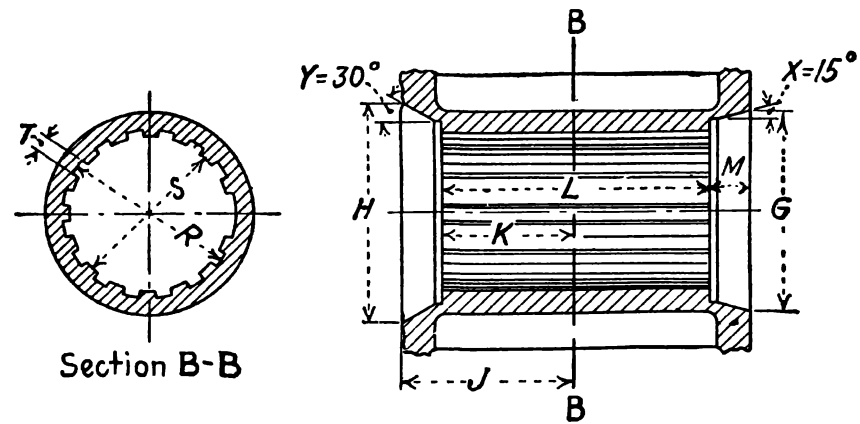


SHAFT

Shaft No.	A	B	C	D	E Effective Length	Thread	No. of Splines
20	2.375+0.000 −0.002	2.156±0.001	0.231±0.0005	2.125+0.000 −0.002	$4\frac{7}{16}$	See note on thread information below table	16
30	2.625±0.001	2.406+0.005 −0.002	0.257±0.0008	2.375+0.000 −0.002	$4\frac{7}{16}$		16
40	3.125+0.000 −0.002	2.875±0.001	0.304±0.0008	2.870+0.000 −0.002	$4\frac{1}{4}$		16

Fig. 801.—S.A.E. Standard Dimensions for Splined Engine Shafts.

The S. A. E. Standards for splined shaft ends are shown at Fig. 801 and for hub interiors at Fig. 802. The No. 1 taper previously shown is for low power engines, the No. 2 taper shaft end is for engines similar to the Wright "Whirlwind" and Curtiss C6, though all indications point to the use of the splined shaft with centering cones on all except the smallest engines of 100 horsepower or less. The threads generally used on the No. 1 taper shaft end are $1\frac{1}{2}$-inch—eighteen (external) American Standard N. F. or $1\frac{5}{16}$-inch—24 (internal) American Standard N. F. The thread in general use on No. 2 taper shaft end is $1\frac{9}{16}$-inch—twelve (external) American Standard N. F., the abbreviation indicating National Fine pitch. The



HUB DIMENSIONS

Hub No.	H Front End	G Rear End	J	K	L	M	R	S	T	Angle X For Rear Cone, Deg.	Angle Y For Front Cone, Deg.
20	3.125+0.005 −0.000	2 875+0.005 −0 000	$2\frac{25}{32}$	$2\frac{3}{16}$	$4\frac{3}{8}$	$\frac{5}{8}$	2.381±0.002	2 162±0.002	0 233±0.0005	15	30
30	3.187+0 005 −0.000	3.187+0 005 −0 000	$2\frac{25}{32}$	$2\frac{3}{16}$	$4\frac{3}{8}$	$\frac{5}{8}$	2.633+0 005 −0.002	2 414+0.005 −0 002	0.259±0 001	15	30
40	3.875+0.005 −0.000	3 625+0 005 −0.000	$2\frac{5}{8}$	2	4	$\frac{5}{8}$	3 131±0 002	2 881±0 002	0 306±0 0005	15	30

Fig. 802.—S.A.E. Standard Dimensions for Splined Propeller Hubs.

thread in use at present on the No. 20 shaft end is 2⅛—twelve American Standard (NF), pitch diameter 2.070 + 0.000, —0.002. The thread sizes in use for shaft No. 30 are 1⅝—sixteen internal thread American Standard (NF) class 3 on the Pratt & Whitney Wasp engine; 2$^5/_{16}$—twelve external thread American Standard (NF) on the engines of the Wright Aeronautical Corporation; and 2⅜—twelve external thread American Standard (NF), pitch diameter 2.320 + 0.000, —0.002, on the Chieftain engines manufactured by the Curtiss Aeroplane & Motor Co. The thread on the No. 40 shaft end as now generally used is 2⅞—twelve American Standard (NF), with a pitch diameter of 2.820 + 0.000, —0.002. The threads on these shaft ends are now under consideration by the Aeronautic Division for standardization.

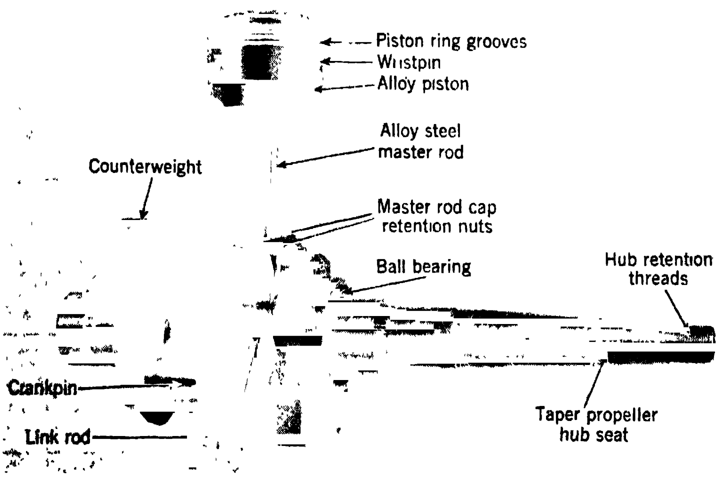


Fig. 802A.—Showing Taper Shaft End of Curtiss Challenger Engine for Propeller Hub Seating.

Fitting New Hub to Shaft.—When fitting new hubs, they should be "lapped" to the shaft to secure a proper fit of the tapers. Remove the key retaining screws and the hub drive key. Use a paste of light oil and valve grinding compound. Turn the hub around on the taper, removing it frequently and cleaning off old abrasive and supplying new. When a full seating is shown, the hub should be further lapped so it will be about .001 inch tighter at the large end of the taper than at the front end. This is done by cleaning off the large end and lubricating it with light machine oil and apply the abrasive only to the small end of the taper. Check the progress of the work by washing off the oil and abrasive occasionally and by testing the fit with Prussian blue. The final result should be reached when the color will spread thin at the large end but remain heavy at the small end of the taper. To mount the hub, insert it in boiling water for two or three minutes to heat it and expand the bore slightly, then tap it lightly in place on the shaft after the key has been put in place and immediately

apply the retaining nut and screw it tightly in place. Then apply the lock nut by screwing it into the shaft until it bears against the flange on the retaining nut. Apply the lock wire, being sure the tongue is long enough to project through both nuts. Be sure there is a clearance of at least .010 inch between the top of the key and the bottom of the keyway in the hub. This method involves removal of the hub from the propeller, but the assembly should have been previously balanced and the propeller installed in the hub in the same position it was before removal. Propellers are often balanced on special mandrels or arbors and this procedure is satisfactory in practice because there is very little chance of the hub, which is machined all over, being out of balance and the lack of balance is usually due to the blades.

Design and Construction of Metal Propellers.—The Navy Department Bureau of Aeronautics in Technical Note No. 161 has covered the subject of metal propellers in a very thorough manner. The paper was prepared by Lieutenant-Colonel Whiston A. Bristow, a well known English authority on aviation. The following excerpts will be of interest to the student or general reader.

It may be as well to set out some of the changes that have taken place in the factors governing propeller design and construction during the past ten years. The chief appear to be as follows:

(a) The increase of top speeds from about 400 feet per second to velocities approaching, and even exceeding, the speed of sound.

(b) The difference in the maximum power absorbed per blade which has increased from 50 brake horsepower to 375 brake horsepower or more coincidentally with a demand for higher factors of safety.

(c) The advent of the supercharged engine as a proved and practicable proposition, and consequently the necessity for a propeller of variable pitch.

(d) The demand for maximum performance either as to height or climb, or a compromise within fine limits, or the necessity for making small alterations after trial, thus involving the use of propellers with adjustable blades.

(e) Aircraft now operate in almost any weather and are often required to fly through rain or hail This factor has exposed the extreme vulnerability of the wooden propeller in this respect.

(f) Commercial and military aircraft are now stationed for long periods in tropical countries. Climatic conditions are all against wood and glue and transport and storage considerations are greatly simplified by the provision of propellers of adjustable pitch and having detachable blades.

In view of the above it would be clearly impossible to introduce at this date propellers of wood if metal propellers were already in general use. Anyone proposing to substitute wood for metal would be regarded as a dangerous person. So great, however, is the conservatism of mankind generally, that wooden propellers continue to be specified, and the advocate of the metal propeller is often looked upon as an experimentalist to be regarded with extreme suspicion.

Consideration of all the evidence in respect to the requirements to be met in the design, construction and operation of propellers leads Lieutenant-Colonel Bristow to the following conclusions:

(1) That by reason of the changed conditions set out in the beginning of the paper, wood can no longer be considered as a suitable material for aircraft propellers.

(2) That steel is the most advantageous substitute from the engineering standpoint, and it also has the advantage of being a home product. (This refers to England.)

(3) That the hollow laminated steel blade can be satisfactorily constructed in such a manner that its tensile strength is sufficiently great to allow it to deal with the inertia and other forces of the great majority of propellers up to top speeds of about 960 feet per second.

(4) That for speeds beyond this there is at present no alternative to the light alloy propeller and that those of the Reed type have proved themselves efficient and able to withstand top speeds beyond the speed of sound and to absorb very high power outputs.

(5) From primary considerations and from actual experience it is considered that it will be found desirable in future in the case of duralumin propellers to make the blades detachable and the hub of steel. The more duralumin is worked the stronger it becomes; therefore, the hub and blade roots which should be the strongest are at present the weakest. This introduces variations in strength which could be mitigated by using rolled plates, the thinner the better. It must also be taken into consideration in designing the hub that duralumin is weaker than steel, weight for weight, and it is only when the very serious centrifugal load is added that duralumin becomes the more favorable material. There is, of course, no need to make the hub specially light, as the centrifugal stresses due to its own rotation are negligible.

(6) It is impossible to make any hard and fast statement as to which type of propeller will be the lightest for a particular job. Solid duralumin is heavier, size for size, than hollow steel, viz.: 1.9 to 1.3 taking wood as 1. This is roughly approximate for propellers up to about eleven feet in diameter. Beyond this length steel becomes relatively lighter and wood and duralumin increase approximately according to the cube law in the case of solid and the square law in the case of the hollow construction. Duralumin, therefore, is heavier than steel in some sizes and lighter than steel in others. In the case of the Leitner-Watts Condor steel propeller which is eighteen feet in diameter this is lighter than if made in duralumin, but if the engine is run ungeared a duralumin propeller becomes possible and would be lighter.

(7) The case for metal as against wood does not rely upon performance. It is satisfactory to note, however, that in a long series of independent tests carried out both at Farnborough and McCook Field metal propellers gave the better performance.

(8) There is every indication that the military aircraft engine of the future will be provided with some type of supercharger necessitating a variable pitch propeller. This will rule out entirely any propeller of the integral type whether of wood or metal, and the ultimate propeller must have separate metal blades.

(9) Quite apart from military considerations there are the fundamental aerodynamic factors governing the changes in the speed of a propeller during the taking-off and flying periods and their important influence on the design and performance of the aircraft itself. A proper solution of the difficulties these present in the opinion of some authorities can only be obtained by the employment of a propeller of variable pitch, i.e., variable in flight either automatically or at the will of the pilot. Each of these two types has been designed, and in some cases tested with most encouraging results.

Reed Metal Propellers.—Dr. S. Albert Reed, the inventor of the Reed metal propeller has furnished the writer with considerable data relative to the development and characteristics of the various types of metal propellers bearing his name. The Reed propeller is an aircraft propeller with solid, thin and almost knife-like blades of forged or rolled duralumin, which alloy has about the same specific gravity as aluminum and the strength of mild

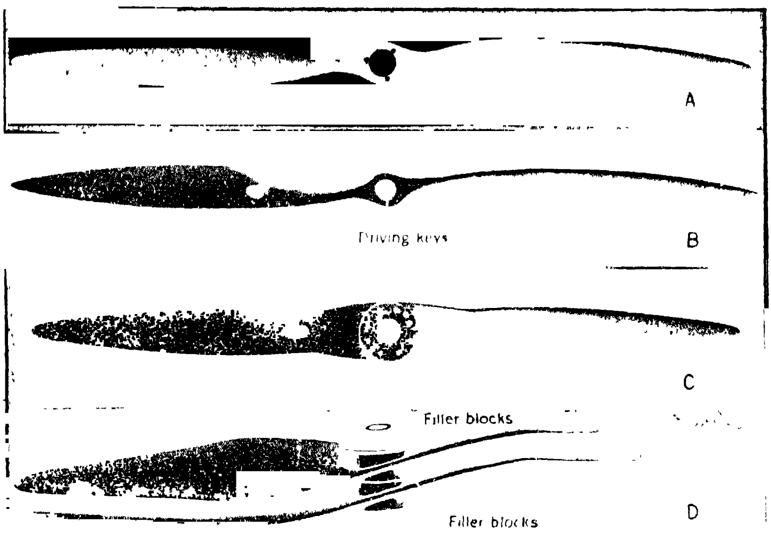


Fig. 803.—Various Practical Types of Curtiss-Reed Duraluminum Propellers. A—Forged Type for Steel Driving Hub. B—Latest Forged Type with Integral Driving Splines for Direct Seating on Engine Shaft. C—Twisted Rolled Blank Type with Filler Blocks for Use in Typical Wood Propeller Hub. D—Biplane Type Using Superposed Type D Propellers.

steel. Such propellers made in a single piece have been manufactured in the United States by Mr. Reed and his licensee, the Curtiss Aeroplane & Motor Co., Inc., since 1921, and since 1923 two other companies have manufactured propellers having detachable blades of the Reed type which are anchored in a steel hub. Since 1923 Reed propellers have been made also in Europe, by five aircraft and metal concerns. The outstanding achievement in the development of the Reed propeller was not merely the substitution of metal for wood but a substantial improvement in the aerodynamic efficiency. The problem was to make a propeller with blades of thin sec-

tions which would not change their pitch, either permanently or in the character of oscillatory change or flutter, and this was accomplished in 1920 after several years' experience with models.

The centrifugal force of each blade of a ten foot propeller at 1,800 r.p.m. is roughly about fifteen tons at the hub. The thrust or pull of such a propeller driven by a 400 horsepower engine is about 1,000 pounds (i.e., 500 pounds for each blade). On account of the inherent rigidity, together with the restoring component of centrifugal force, the forward tip deflection in flight, due to thrust, is usually less than one inch, either with a wood or a metal propeller. The aluminum alloys used for Reed propellers are the following:—Baush duralumin; Vickers duralumin; Duren duralumin; Aluminum Co. of America 25 S; Schneider & Co. (France), Alforium, and Metallbank und M G. (Germany), A eron.

The present D type of propeller is a refinement of the original Curtiss-Reed Propeller which was tested in 1921. It is made from a flat slab of duralumin, machined to the proper contour and twisted to the required pitch. The conventional type of engine hub is used, with wooden filler blocks used as spacers between the face plate and the blade. Careful refinement of design eliminates any danger of failure at the hub bolt-holes. This form is shown at C, Fig. 803. This type of propeller first received official recognition in 1923, when the Curtiss-Navy racers which took first and second places at record-breaking speeds in the Schneider Cup Race in England, and the Navy-Curtiss racers which duplicated this feat in the Pulitzer Race in the United States, were equipped with Curtiss-Reed Propellers. Military and commercial services alike were quick to appreciate their remarkable performances, and by 1925 the value of the Curtiss-Reed Propeller had become so definitely established that the Collier Trophy, given annually for the most valuable contribution to aeronautics, was awarded to Dr. Reed. Today there are several thousand Curtiss-Reed D type propellers in service in the United States and abroad, with a total flying time of considerably more than a million hours, which figure is increasing daily.

To meet the requirements for an exceptionally efficient propeller, of great strength and capable of withstanding high speeds, the "R" type of Curtiss-Reed Propeller has been developed. It has been made in two forms, one adapted for the use with a flanged hub as shown at Fig. 803 A, the other has splines directly in the boss, as shown at Fig. 803 B. This propeller is a die-forging from a solid ingot of aluminum alloy. This method of manufacture permits the carrying of the true blade angles directly into the hub, and combined with the thin blade sections inherent in all Curtiss-Reed types, provides high propeller efficiency. The usual type of engine hub is entirely done away with, and the propeller is either splined directly to the crankshaft or fitted with a steel sleeve which is keyed to the crankshaft. There are no hub bolt holes in the latest form and the solid rugged hub provides exceptional strength and rigidity, as well as eliminating much of the noise which is characteristic of some metal propellers. The Curtiss-Reed propeller has many record-breaking performances to its credit, of which the most recent are the winning of the 1927 Schneider Cup Race by the

British Supermarine seaplane at the tremendous speed of 281.6 miles an hour, and the subsequent establishment of a new world's record of 298.8 miles an hour by the Italian Macchi seaplane. The Macchi propellers were built by the Curtiss Company. The "R" type of propeller is now being furnished in large quantities to the U. S. Army, Navy, Marine Corps and National Guard, for use on the latest types of military aircraft, where high performance and reliability are vitally necessary. It is also being widely adopted by commercial manufacturers and operators who are desirous of having the most efficient types of propellers on their aircraft.

The first type of Curtiss-Reed propeller was known as the Z1 and was first flown August 30, 1921, at Curtiss Field, by C. S. Jones, the Z2 in June, 1923. Attention of the aircraft world was soon attracted by the outstanding features of type Z, its superior performance, its ability to give good performance at high tip speed, its superior conduct in bad landings, its superior durability, and its superior resistance to vicissitudes of climate and weather. In fact here was a type which not only seemed to solve the metal propeller problem but also aerodynamically marked a very substantial advance in efficiency. Propeller efficiencies had been 75 per cent to 80 per cent. Type Z propeller efficiencies were from 80 per cent upwards.

The three kilometer record, held till recently by Bonnet in France, was won in a Bernard Hispano plane with a Z1 propeller made in the United States by Curtiss. The Italian Macchi-Fiat Schneider winner of 1926 used Z1 propellers made in the United States by Curtiss. The British Supermarine-Napier Schneider winner of 1927 used a Fairey-Reed Z1 propeller of type D made by Fairey of England. The Italian-Macchi-Fiat three-kilometer winner of 1927, flown by de Bernardi, November 5, used a Z1 propeller made in the United States by Curtiss and achieved a speed reported at 298.7 miles per hour. In addition many remarkable long distance records including Byrd's North Pole and Lindbergh's New York-Paris flight have been made all over the world with regular service propellers of type Z. The efficiency of these wonderful racing propellers is estimated at more than 87 per cent. Any mechanical device which functions to 87 per cent efficiency ranks in the first row, and with only thirteen per cent left the probability of further improvement is not great.

To determine actual flight efficiency of a propeller a thrust meter flight attachment is necessary, and so far none has been produced meeting all requirements, but it is understood that the U. S. Army Air Corps engineers will soon have one which is satisfactory and we will then have exact data on propeller effiiency in actual flight. Theoretical reasoning seems to show that low pitch ratios are less efficient than high, and this argument is used to favor the geared drive over direct drive for high speed engines at low flight speeds. The basic data of the mathematical reasoning on this subject are not very exact, and future experimental data with the new apparatus may be desirable. The body interference factor of course is less favorable with the small diameter propeller. With these new facilities for propeller research provided by the U. S. Government, the Aircraft Industry will be able to prosecute individual investigations of value, relating to propellers.

Manufacture and Tests of Reed Propellers.—Z1 propellers are either of the D type, made from rolled plates twisted at the center to establish the

maximum pitch angles close to the hub and adapted by the use of filler blocks to be mounted on the same hubs used for wooden propellers; or A type—the same as D—but mounted on a special steel hub and avoiding the circle of bolt holes necessary in D type—or else of R type from a forged bar and with die forged centers. In both cases the blanks come from the metal works in annealed condition and are heat-treated or aged after twisting. In Europe, where the Reed patents are quite generally observed, only the D type of Z1 is so far manufactured by licensees. Z2 blades are die forged, with pitch angles complete, from forged bars and then heat-treated or aged. There has been a troublesome early stage in the history of production of these die forgings, which have to comply with rigid Government requirements and inspection. Many rejections have now led to a mastery of the subject by the manufacturers of the alloy. Die forging processes of this type need close supervision to avoid errors of manipulation which may result in locally inferior physical qualities escaping routine inspection. The rolling process, producing plates of uniform thickness from which the propeller blanks are afterwards made, is of a more routine character and is less likely to experience errors in manipulation leading to locally inferior physical qualities and to some extent a propeller made from a rolled plate may be preferable. An intelligent and capable metallurgical expert department head is now really a necessity for any manufacturer of light alloy propellers. Recently the extrusion method of producing from the ingot the bars used in the die forging has been undertaken and it is believed will result in more reliable forgings.

Recently special deflection tests have been made at McCook Field and at the Curtiss factory to determine what the deflection would be without the straightening influence of centrifugal force. In these tests the propeller was supported with its hub on a block and with driving face up and blades were then loaded with a distributed load equivalent to the calculated service thrust loading, and the deflections noted. It was found that a ten foot type Z propeller for Liberty engine deflected ten per cent of the blade length and a ten foot wooden propeller for Liberty engine deflected about three per cent. As neither propeller in flight would probably have a tip deflection over one per cent of the blade length, it is obvious to what degree centrifugal force is an essential element in each type and this degree may be taken as a measure to define what is meant by the term thinness as applied to a blade. In that sense "thin blade" means thin with relation to its intended thrust load. The blade of a ten foot Liberty propeller has a thrust load of about 500 pounds and a centrifugal load of over ten tons. The blade of an electric fan may be only $\frac{1}{16}$ inch thick but as the thrust load on the blade is less than a pound, the blade is not a thin but a thick blade in the above sense.

In *Aviation*, April 25, 1927, Dr. Reed described a novel arrangement of two Z1 type propellers mounted on the same hub, in tandem, with the blades parallel, making a biplane arrangement as shown at Fig. 803 D. This propeller had a successful ten-hour whirling test at McCook Field with 50 per cent overload, and was flown at Curtiss Field with excellent performance. It is equivalent to a regular four blader, and has the same efficiency, even with only four inches interspacing. The plan had already been

worked out by Dr. Reed in 1922, and a three foot model tested in the wind tunnel at Stanford University by Professor Lesley, and there has been some surprise expressed at absence of blade interference. To mount two propellers made "in tandem" on the same hub, without increasing the overhang, is especially easy with the Z1 propeller of D type made from rolled plate and twisted at the center. There are special conditions where this type is likely to be of much importance.

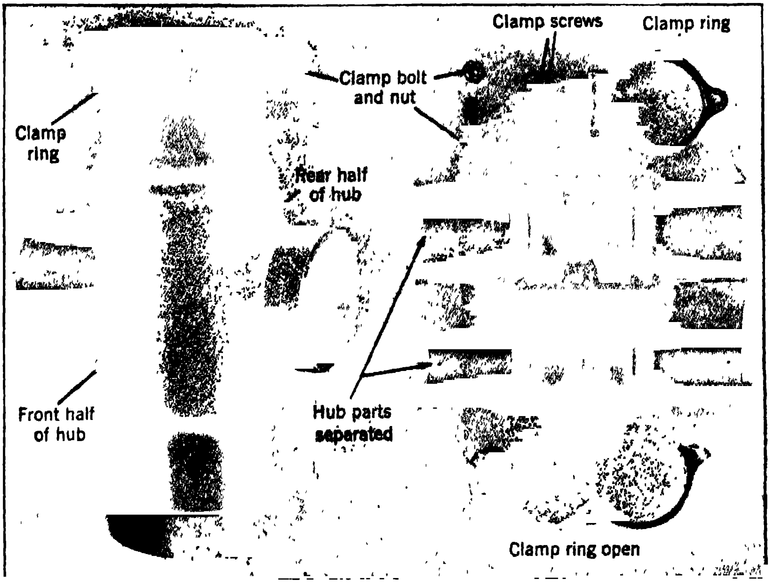


Fig. 804.—Split Hub Construction for Two-Blade Standard Steel Propeller.

Standard Steel Propellers.—The Standard Steel Propellers are different from all earlier types of propellers in that they are made up of an alloy steel hub and detachable aluminum alloy blades which can be adjusted for pitch. The hubs are made in two parts as shown at Figs. 804 and 805 being split down the center of the hub barrel in the plane of revolution. The two halves are held together by clamping rings at the end of the hub barrel and by the retaining nut which holds the propeller on the engine shaft. For convenience in assembly two small cap screws are provided at the center of the hub to hold the two halves of the hub together, prior to assembly on the engine. All blades are made interchangeable as to balance at the factory, so that a damaged blade can be replaced by a new one and the propeller will still be closely in balance. As a final adjustment of the balance a mandrel is passed through the center of the hub and the propeller is suspended on knife edges. With the blades in a vertical position, the clamping rings are shifted by turning them slightly on the hub barrel until the balance is perfect. All centrifugal force on the blades is resisted by the substantial collars on the ends of the blades, which fit against corresponding abutments in the hub forging as shown at Fig. 806.

A typical two blade assembly is shown at the top of Fig. 806. The driving forces against the blade end are taken by the long blade socket of the hub.

Too much care cannot be given to balancing a propeller. A metal propeller, properly balanced should run very smoothly, insuring comfort to the pilot and relative freedom from maintenance difficulties due to vibration. Not all vibration, however, can be blamed on the propeller, because faulty carburetion or distribution will also cause it, particularly in metal structures. Setting the pitch of the propeller where a checking plate and protractor are available, the pitch angle of the propeller may be set by laying the assembled propeller on the checking plate with the flat face of the blades up, and loosening the clamping rings. The pitch may then be adjusted

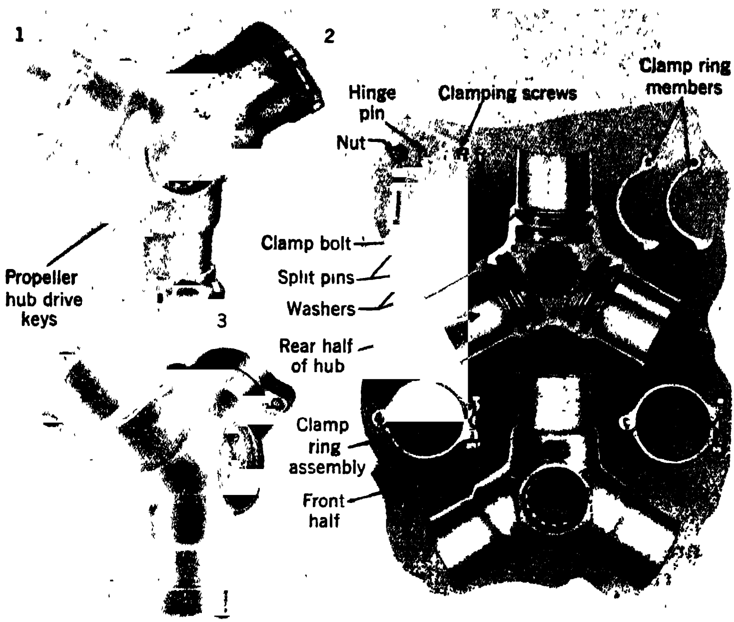


Fig. 805.—Split Forged Steel Hub for Three-Blade Standard Steel Propeller Showing All Parts.

by tapping the blades with a leather or rubber mallet until the desired angle is obtained. The fit of the blades in the end of the hub next to the engine is made free so that it is unnecessary to loosen the cap screws which hold the two halves of the hub together.

In order to facilitate setting the pitch where no checking plate is available, and to make it possible to adjust the pitch without removing the propeller from the engine, a scale is marked on each end of the hub and a line scribed on the blade. This scale reads the angle setting of the blade in degrees at the 42-inch radius and is shown at Fig. 806. To set the pitch without removing the propeller from the engine it is only necessary to loosen the two clamping rings and tap the blades with a leather or rubber mallet until the scale reads the desired pitch setting. A useful rule to

apply in adjusting the pitch on propellers for Wasp engines as an example is the following:—Change the pitch by one degree for each 60 r.p.m. by which it is desired to change the engine speed at full throttle; to slow down the engine, increase the pitch setting; to speed up the engine, decrease the pitch setting. Special propellers are needed for each engine though the general construction is the same for all sizes. Once balanced a propeller should need little attention to balancing until enough metal has been eroded or chipped away to change the weight distribution. This condition is apparent as soon as it occurs and the remedy is obvious.

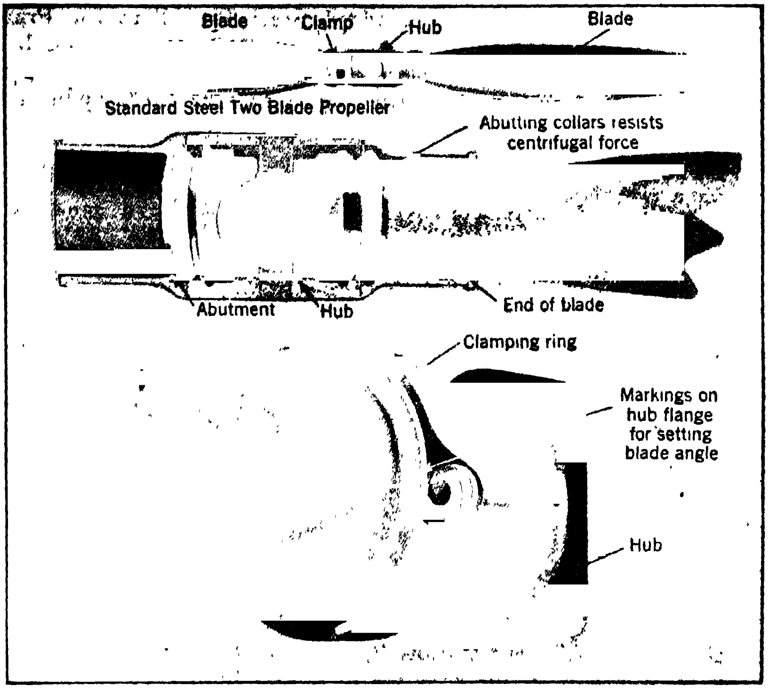


Fig. 806.—Standard Steel Two-Blade Propeller Assembly Shown at Top. Part Sectional View Below it Shows Method of Blade Retention. Bottom View Shows Markings on Blade and Hub Flange to Aid in Setting Blade Pitch.

Whenever there is any sign of pitting at the leading edge of the blade, it must be attended to immediately. If the pitting is at all bad the rough edges must be smoothed down with a fine file, the whole leading edge smoothed down with emery cloth and finished with crocus cloth. However, the file should be avoided if possible and be used only when the pitting is so extensive as to make its use necessary. Occasionally, when severe pitting occurs, it may be necessary to remove so much material that the propeller becomes unbalanced. This condition must be watched for and be corrected if it occurs. Ordinarily, propellers are issued bright—that is, without either paint or protective coating. The best protection for the metal is a thin coat of oil, which should be applied by wiping the blades

with an oily rag. This can be done best after the tips have been touched up with the emery and crocus cloths to remove roughness.

When blades are damaged, due to bad landing, etc., it is often possible to straighten them so they may be continued in use. In order to do this, however, the blades have to be annealed first, and heat treated again after straightening. The blades must then be etched with a suitable solution and carefully examined for cracks before being put back into service. On account of the equipment required to straighten these blades, they should be returned to the factory where the work can be properly done for a reasonable charge.

Recommended diameters for Standard Steel Propellers for Pratt & Whitney "Wasp" engines at different airplane speeds are given below. These diameters are correct when the full power of the engine is used and the pitch is adjusted to allow the engine to turn 1,900 r.p.m. at full throttle.

Speed of the airplane in miles per hour..	60	80	100	120	140	160	180	200
Diameter for a two-blade propeller ...	12′	11′1″	11′	10′6″	10′	9′9″	9′6″	9′3″
Approximate weight of each blade .	41.0	38.0	33.0	29.5	27.0	25.9	24.3	23.6
Diameter for a three-blade propeller .	11′	10′9″	10′	9′6″	9′3″	8′9″	8′6″	8′3″
Approximate weight of each blade .	33.0	31.3	27.0	24.3	23.6	21.3	20.3	19.3

Approximate weight of two-blade hub—25.5 lbs
Approximate weight of three-blade hub—42 lbs.

Below are the diameters recommended for Standard Steel Propellers for the Wright "Cyclone" engines at different airplane speeds. These diameters are correct when the full power of the engine is used and the pitch is adjusted to allow the engine to turn 1,900 r.p.m. at full throttle.

Speed of the airplane, in miles per hour	100	120	140	160	180
Diameter for a two-blade propeller	11′2″	10′8″	10′2″	9′10″	9′6″
Approximate weight of each blade (pounds) ..	35	32	29	27	25
Diameter for a three-blade propeller	10′4″	9′10″	9′4″	9′	8′8″
Approximate weight of each blade (pounds) . .	28	26	24	22.5	21

Approximate weight of two-blade hub, 47 lbs.
Approximate of three-blade hub, 40 lbs.

Propellers More Efficient at Low Speeds.—In the development of aviation engines, it has been the practice to obtain higher power output by increasing the speed of rotation. In this way, engines of lower weight per horsepower have been obtained but with a resulting increase in propeller speeds. Experience and theory each indicate that increased propeller revolutions bring reduced propeller efficiency, hence all of the gain in engine power obtained by increased rotational speed is not transformed into gain in propeller thrust horsepower. With a high-speed propeller, the loss of efficiency is considerably greater during climb and take-off than at high airplane speeds. The high-speed propeller is therefore particularly unsuited for transport and commercial airplanes where high thrust power during climb and take-off is necessary. Of course, as speeds are reduced, pitch and diameter must be increased in the proper proportions.

To obtain light-weight powerplants and at the same time overcome the lack of efficiency of the high-speed propeller in a commercial or military weight-carrying airplane, it is necessary either to use propeller reduction

gears with the ordinary crank type engines, or to employ the Fairchild Caminez engine. With the Caminez cam mechanism the power output is obtained at one-half of the speed of a crank engine having the same piston speed. An example of the gain in performance obtained by use of low propeller speed is clearly shown in the accompanying table.

*OFFICIAL PERFORMANCE TESTS OF A U. S. GOVERNMENT TRANSPORT AIRPLANE

With Direct Drive 400-Hp. Engine

			Climb			
Altitude feet	Speed m.p.h.	Engine r.p.m.	Time min.	Rate ft./min.	Level r.p.m.	Flight m.p.h.
0	68.2	1660	...	280	1795	98.7
5000	69.7	1660	24.2	145	1740	92.2
6500	70.0	1657	36.0	105	1720	89.0
6650*	70.1	1655	37.6	100	1718	88.5
10300†	71.0	1625	.	0	1625	71.0
			With 2:1 Geared Drive 400-Hp. Engine			
0	71.2	1655		618	1900	108.3
5000	70.7	1640	10.6	348	1830	101.2
6500	70.4	1630	15.5	265	1800	98.4
9600*	70.1	1615	33.6	100	1715	90.4
11400†	69.8	1595	....	0	1595	69.8

* Service ceiling. † Absolute ceiling.

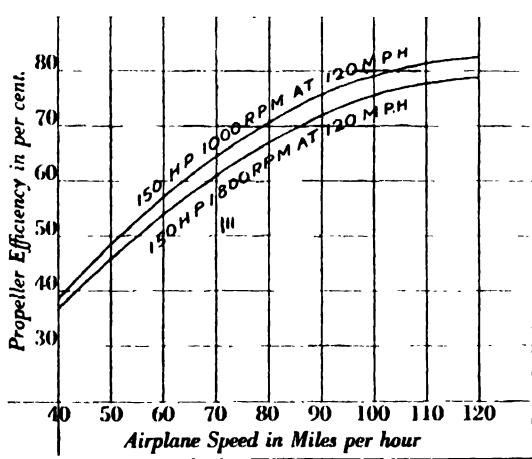


Fig. 807.—Calculated Propeller Efficiencies of Low-Speed and High-Speed Propellers in Level Flight Shows Superiority of Low-Speed Screw.

Aircraft Propeller Design.—Lieut. Commander Clinton H. Havill, U.S.N., presented a very interesting and informative paper on the subject of "Aircraft Propellers" at the Aeronautic meeting of the S.A.E., Inc., held at Chicago, Ill., Dec. 5th and 6th, 1928. This paper was accompanied by charts based on analysis of performances of service propellers which are

reproduced from the paper as well as a number of excerps which reflect the experience of the U. S. Navy Bureau of Aeronautics obtained with a number of phases in connection with the use and testing of adjustable blade propellers.

Design of aircraft propellers of the detachable blade type, adjustable in pitch on the ground, has become a special branch of aeronautical engineering. This type of propeller has primarily been developed in this country, and nearly all the propellers used by both the Army and the Navy are of this type. The Navy has found it necessary to make its own designs and to furnish the propeller manufacturers with finished detail drawings. These designs are largely used in commercial aviation, designated by the manufacturer's number instead of by the original design number. The reason for this is that, for a given type of engine and airplane and for a given airspeed, the Army and the Navy have developed a propeller blade that "fits" the airflow; and for similar conditions the commercial operator secures the benefit of the design and experimentation on propellers that the military services have found necessary.

Lieut. Commander Havill states that it seems logical to ask if, from all the propeller literature and the hundreds of previous types of planes, it is not possible to furnish a propeller that is the best for those conditions. The answer is that it is possible to furnish a propeller that is accurately designed and that will give excellent performance; but it will not always be the best propeller. Although the difference between a good propeller and the best may appear small to the average pilot, yet when such things as fuel consumption per mile and ability to take-off with a very large load are considered, it can be seen that the best propeller for a given plane must be especially suitable for the things that the plane is designed to do. To provide such a propeller, the designer often must sacrifice one to two m.p.h. of top speed to favor a higher rate of climb, as is done in some fighting planes. In other cases it may be necessary to sacrifice a little on rate of climb to favor fuel economy at cruising speed.

Best top speed seldom is given by the propeller that is best, all things considered, except in racing planes. However, in racing planes, the ability to change the top speed by small changes in the design of propeller is limited usually to a small percentage of the total speed, as, in racing, the propeller works under conditions that favor high efficiency, if the diameter is nearly correct; and the speed changes only as the cube root of the change of efficiency, expressed as a percentage. Horsepower and "clean design" of plane are the items that win most aircraft races.

Sources of Designer's Information.—The designer of aircraft propellers has several sources of information, no one of which, except experience, is sufficient in itself always to give the best propeller at the present state of the art. These sources may be tabulated as follows:

(1) Pure theory:
  (a) Momentum theory.
  (b) Blade-element theory (Drzewiecki, 1909).
  (c) Combined momentum and blade-element theory, giving rise to a modified theory.
  (d) Prantle's theory of wings, developed by Bates to apply to propellers and finished in practical form by Glauert.

(2) Wind-tunnel tests:
  (a) Model tests.
  (b) Full-scale tests, with and without fuselage (now being carried on by the National Advisory Committee for Aeronautics).
(3) Analysis from actual service-flight tests.

A great amount of pure theory is available, and nearly as much in the way of data from wind-tunnel tests is at hand in various forms; but not so much has ever been published based on free-flight tests of metal detachable-blade propellers.

Chart Based on Propeller Analysis.—Chart 1 shows the result of the analysis of a large number of service propellers for various types of airplane. Cases were chosen in which the propeller performance was considered entirely satisfactory, if not the best; so, by following the instructions on Chart 1, a diameter and setting of a pair of detachable blades can be found that will give reasonably good performance for nearly any horsepower, number of revolutions per minute and airspeed commonly used on direct-drive propellers today.

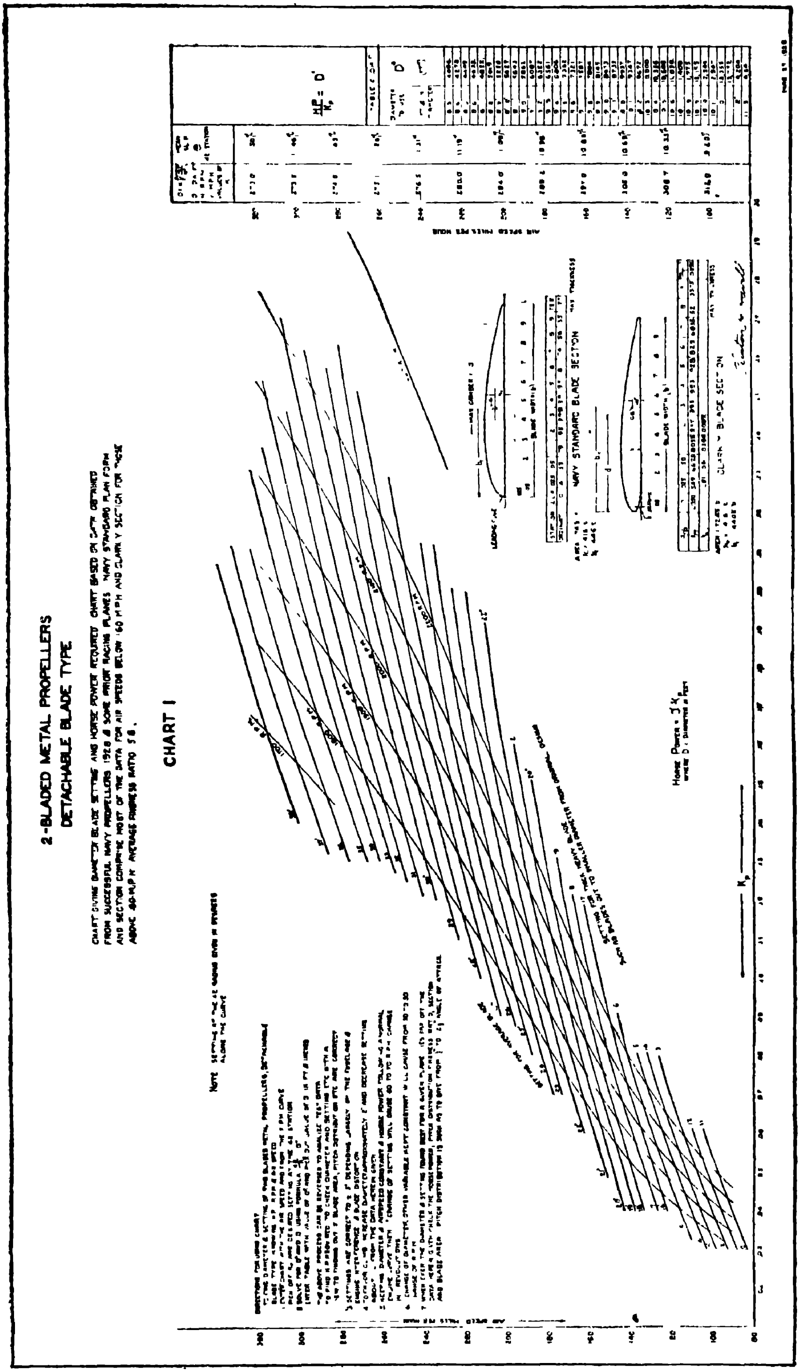
To use the chart: (a) enter it with the airspeed, and from the r.p.m.-curve pick off K_p and the desired setting at the 42-inch station; (b) solve for D^4, using formula $HP/K=D^4$. Then enter the table with the value of D^4 and pick out the value of the diameter in feet and inches.

This chart cannot be used backwards; for example, if a plane normally makes 140 m.p.h. and then, from the chart, a propeller is chosen which is of the diameter and setting for a 150-m.p.h. plane, the 150-m.p.h. propeller probably will give a speed of only about 135 m.p.h. to the plane having a normal speed of 140 m.p.h. Horsepower available and propeller limiting efficiencies prevent the chart being used in the reverse order. It is the same as in any other branch of transportation, the power available and the efficiency attained govern the performance.

Chart 1 was produced by Lieut. Commander Havill in the Propeller Section of the Bureau of Aeronautics for general office use. It furnishes data for a propeller based on the mean of previous performance and will give a propeller of good propulsive efficiency, though not always the best propeller, as will be explained later.

Theory versus Practice.—Before proceeding it should be stated that the results of pure theoretical study, wind-tunnel tests and actual service use are not in entire agreement. Pure theory is, of course, the basis of all real progress in any branch of engineering and, as such, must be kept constantly developed. A solid groundwork of pure theory in propellers is necessary if one is to attempt to extend practical results properly from one condition to some other assumed condition. Wind-tunnel tests of model propellers is the next step. Model tests have greatly aided in furnishing the modification necessary to "pure theory" and have served to develop the blade-element theory to the point at which a propeller can be designed accurately, even if it is not the best propeller. Use of the radial air-cooled aircraft engine has necessitated many changes in the previous methods of applying model tests to actual use.

There are a number of sources of discrepancy between model tests and the full-scale tests, and also among the full-scale tests themselves. The most


2-BLADED METAL PROPELLERS
DETACHABLE BLADE TYPE
CHART I
NAVY STANDARD BLADE SECTION
CLARK Y BLADE SECTION

common one is the well-known scale-effect that is assumed to depend on the Reynold's number, which is a nondimensional number depending on the size of the model, the velocity of the air, and the density and viscosity of the air during the test. The theory of similitude shows that, for the same value of Reynold's number, the same airflow and forces exist; however, this does not appear to hold exactly true for propellers. A second source of discrepancy is the tendency of the propeller blades to distort under load, causing changes in the nature of the flow across a propeller blade. This is especially important if the pressure distribution is altered on account of change of flow. A third cause of differences is the interference of the engine, fuselage and airplane adjacent to the propeller. These interferences change the inflow and greatly affect the propeller performance as well as causing a turbulent slipstream, with its consequent higher drag on all parts of the airplane in contact with it.

A fourth cause of discrepancy is the change in flow occurring at high tip-velocities. This change in flow, which may be a compressibility effect near the velocities of sound, or about 1,100 feet per second, has been investigated and much has been written on the subject. (See National Advisory Committee Reports Nos. 83, 207 and 255; also British Aeronautical Research Committee's Reports and Memoranda 1,086, 1,123, 1,124, 884.) However, all propellers seem to lose some efficiency for tip speeds beyond 900 feet per second, and the amount of this depends on the ratio of blade thickness to blade width for sections near the tip, the type of airfoil used, the angle of attack, the pitch and the pitch distribution. In view of these principal discrepancies, it is not surprising that propeller-model tests cannot be used directly for full-scale propellers. For example, the net result of the application of 30-inch-diameter-model tests is that the power coefficient obtained on a model must be multiplied by 1.86 as an average correction to apply to the power coefficient used on nine-foot-diameter geometrically similar propellers.

Model tests have their proper usefulness in the propeller art, but there are too many idiosyncrasies in trying to use empirical correction-factors to full-scale actual propellers. But, as a matter of convenience, model tests are of more actual use than the direct application of pure theory in the abstract.

Full-Scale-Propeller Wind-Tunnel Tests.—The result of all these previous labors has been for the National Advisory Committee for Aeronautics to build a twenty-foot diameter wind-tunnel so that a full-scale propeller can be tested together with its engine and fuselage. The results on the first tests made recently have been somewhat discouraging. The power coefficients appear low and the efficiency rather high, while the thrust apparently agrees closely with previous methods of calculation. The method of testing is to measure the thrust and torque of the actual propeller while driven by the engine. From these quantities, thrust and power coefficients are calculated so that, for other conditions, the results can readily be attained.

The following formulas are used based on similitude:

$$T = C_t \rho N^2 D^4 \qquad (1)$$

where C_t, C_q and C_p are functions of (V/ND) curves being plotted of these functions.

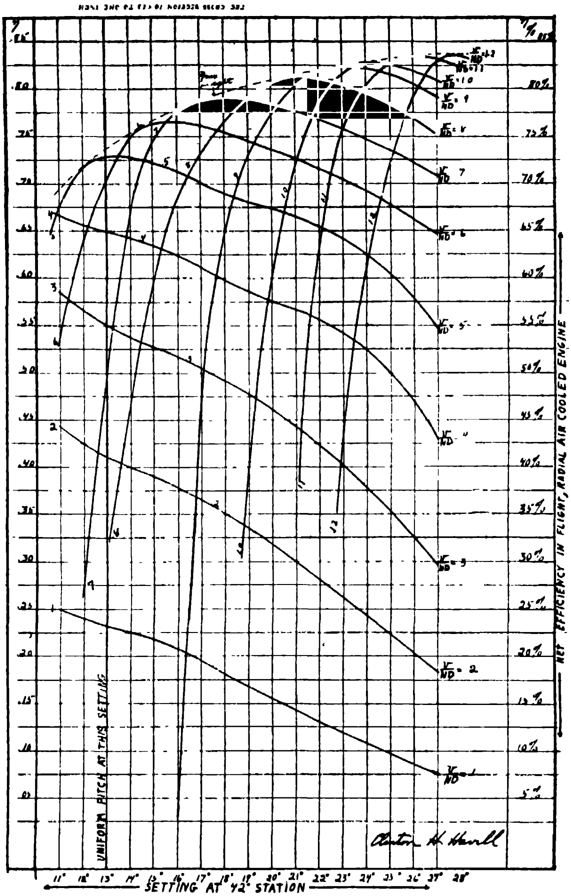


CHART 2

7NET VS SETTING FOR CONSTANT VALUES OF($\frac{V}{ND}$)

9FT DIAMETER TWO BLADED PROPELLER.
FLIGHT CONDITIONS WITH RADIAL AIR COOLED ENGINE.
5FT PITCH UNIFORM, TURNED UP

CALCULATED FROM FLIGHT TESTS OF 3792-9, NACA TEST OF 9912-9, R+M 103 Y+ DURANTS DATA.

$$Q=C_q \rho N^2 D^5 \qquad (2)$$

$$P=C_p \rho N^3 D^5 \qquad (3)$$

The symbols used, in English units, are as follows:

T=Thrust, in pounds.

ρ=Density of air in the tunnel, or g times the number of pounds per cubic foot.

C_t=Nondimensional thrust coefficient.

N=Number of revolutions per second.

D=Diameter of propeller, in feet.

Q=Torque, in pound-feet.

P=Brake horsepower—Power in foot-pounds per second.

C_q=Nondimensional torque coefficient.
C_p=Nondimensional power coefficient.
V=Airspeed, in feet per second.

In theory, C_t C_p C_q remain constant for a geometrically similar propeller operating at the same (V/ND). The same values of thrust coefficient, C_t, and power coefficient C_p, could be used for free-flight theoretical computations provided the coefficients were obtained at full scale in the wind-tunnel. However, this application does not seem to work out in practical propellers because the wind-tunnel power-coefficients are usually low. Various explanations have been advanced, but the most commonly accepted one is that, in the wind-tunnel, an "artificial inflow" is caused which lowers the power and thrust coefficients. This lower thrust results in less distortion of the blade than is found in free flight, while wind-tunnel efficiency is usually two to three per cent higher than free-flight analysis would indicate.

Free-Flight Efficiencies.—An example of the actual efficiencies attained in free flight with one particularly thin blade used on direct-drive air-cooled engines is shown in Chart 2. This blade is an instance of a low uniform pitch turned to higher effective pitch. This gives rise to a pitch distribution. For example, this particular blade, Bureau of Aeronautics design No. 3,792 and nine feet in diameter, is used on certain fighting planes when set nineteen degrees at the 42-inch radius. Complete data on this blade are given in Chart 3. The pitch at the tip is then 8.17 feet; at the 36-inch radius it is 7.20 feet; and at the 13-inch radius it is 5.78 feet. The necessity of such a pitch distribution means that the airflow around the hub and over the cylinders of the air-cooled engine causes the propeller to work in a nonuniform airflow. The engine is cooled better if the pitch is increased near the hub, but the net propulsive efficiency of the propeller designer must compromise between cooling the engine and getting the best effective thrust for the airplane This compromise is best effected by having the pitch distribution fit the airflow in such a way that an efficient angle of attack is maintained at each section. Experience and analysis of flight tests appear to be the best teacher of this. It is possible to fly almost any airplane in the Navy with one of four or five basic designs of blades by cutting off the tips to the correct diameter and setting the blades at a pitch to give the required number of revolutions per minute. However, these methods rarely give the best fuel consumption per mile; that is, the best propulsive efficiency. In the foregoing statement, the strength of the blades is not considered; it will be discussed later.

Actual Efficiency Below Test Efficiency.—In the past, propeller efficiency has been adopted as a simple and practical criterion of the excellence of the propeller performance, and this is still true provided the proper definition of efficiency is used. It is wrong simply to place a propeller in a wind-tunnel, measure its efficiency under a given condition, and assume that the same efficiency is to be attained in a practical case with an actual airplane in flight. Certain propeller manufacturers have talked of the high efficiencies of their propellers, quoting tests showing 90 per cent efficiency; however, the true or net propulsive efficiency is usually lower than that measured in a wind-tunnel. As an example, assume that a propeller devel-

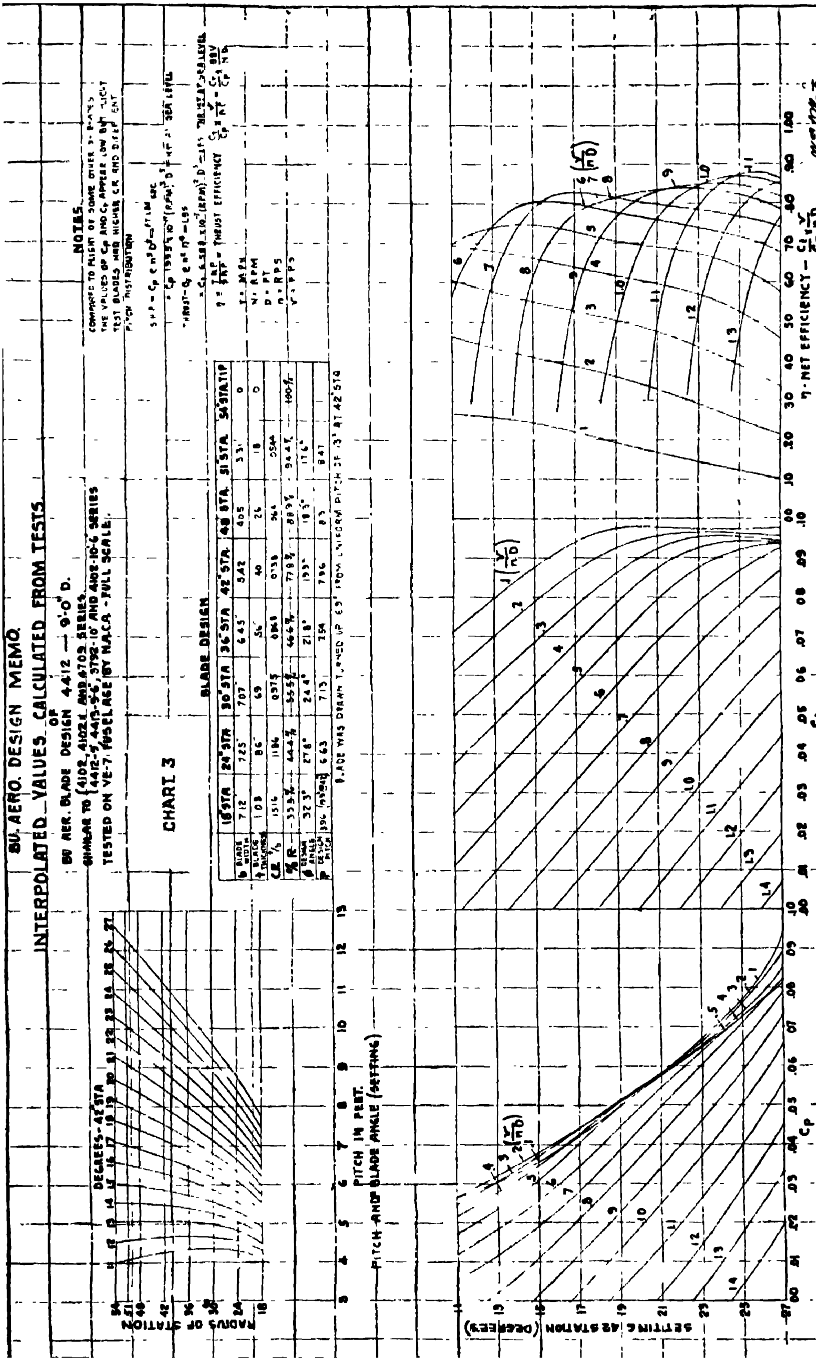
ops 800 pounds of thrust and further, that the slipstream velocity creates 50 pounds of drag on the engine, fuselage and wings, this drag being caused solely by the difference between the drag at the speed of the airplane and the drag at the speed of the slipstream Then there is only 750 pounds of useful thrust and, of course, the propulsive efficiency is lower than that found on test in the free atmosphere of a wind-tunnel. As in ship-building parlance, it is the "propulsive efficiency" that counts; therefore, a given propeller arrangement should be judged entirely on that basis.

In attempting to analyze wind-tunnel data and actual flight-test data, a general conclusion can be reached that, with heavier-than-air tractor propellers, about two to three per cent of the efficiency is lost as compared with wind-tunnel data. Chart 2 is an efficiency chart showing the net propulsive efficiency as Lieut. Commander Havill has calculated it for a detachable blade widely used on the Navy fighting planes with radial air-cooled engines. It is to be noted that the method of plotting the curves in Chart 2 is not the conventional method of propulsive efficiency, versus V/ND; but propulsive efficiency versus setting with curves of constant V/ND. This method offers itself more readily for office and field use. It is believed that the waves in the curves are caused by blade distortion, together with changes in the inflow velocity.

Much more could be said about the propulsive efficiency of various arrangements of propellers and engines. It appears that a pusher propeller located astern of the trailing edge of the wings gives the best effective thrust from a propeller standpoint, but is not so good when the best locations of the principal weights, such as that of the engine, are considered. However, the present conventional tractor propeller ahead of the engine, on the nose of the airplane, has fairly good efficiency even if it is not the best. It appears that the propeller and the engine break the smooth flow of air about three feet ahead of the propeller. The result is that the use of a small spinner usually produces no observed change in airspeed. The usual conventional type of spinner can be used or removed, so far as performance is concerned, for airplanes having a normal speed of about 150 m.p.h. or less. Commercial airplanes usually are fitted with a small propeller-spinner because it improves the looks and is a good selling point.

Substitute Propellers—Whenever the proper design of blade for a specific propeller is not available, airplanes can be kept in the air by using substitute propellers. These are made up by using blades of another design and of larger diameter that are kept on hand. These large blades can be cut down to the desired diameter, according to the diameter formula, and set to give the desired number of revolutions per minute. The general effect of substitute propellers is a loss of top speed of from one to five m.p.h.; climb and take-off may be slightly better or worse. The diameter formula is as follows, and it should be noted that the number of revolutions per minute and the horsepower must be consistent for the type of engine on which the propeller is to be used.

$$D = K \sqrt[4]{\frac{HP}{(RPM)^2 V}} \qquad (4)$$


BU. AERO. DESIGN MEMO.
INTERPOLATED VALUES CALCULATED FROM TESTS
OF
BU. AER. BLADE DESIGN 4412 — 9'-0" D.
CHART 3
BLADE DESIGN
NOTES
PITCH IN FEET.
PITCH AND BLADE ANGLE (SETTING)
DEGREES-42" STA
RADIUS OF STATION
SETTING 42" STATION (DEGREES)
η - NET EFFICIENCY
V/nD CURVES

In equation (4), V is stated in miles per hour and represents airspeed. The value used should be three m.p.h. less than the top speed of the airplane when fitted with the correct propeller. The diameter in feet is represented by D. K is taken as being 300 for a two-bladed and 285 for a three-bladed propeller.

For reasons of aerodynamic balance it is important that the same contour of tip be put on all the blades of the same propeller and that good balance be had before attempting to take the air. A template of thin metal can be used to form the tip on the first blade, and the other blades can be cut to conform with this template. The settings should be such as to give the number of revolutions per minute used in the formula. This is usually about one degree less than the standard service-setting used for the correct propeller. If in doubt as to the initial setting for the first trial, the following formula should be used:

$$\tan \quad \frac{4.37\ V}{RPM} \tag{5}$$

Calculation of Primary Stresses.—The method of calculating the primary stresses in a propeller blade is to plot a curve of the intensity of centrifugal force for 25 per cent in excess of normal revolutions, at stations taken at each six inch of radius. The area under this curve equals the total centrifugal force, since centrifugal force equals (Mv^2r). The curve of total centrifugal force, CF, is plotted against the length, or radius, of the blade starting with $CF = O$ at the tip and maximum at the blade root. By dividing the total force at any radius by the cross-sectional area of the blade at that radius, the fiber-stress caused by centrifugal force is obtained. The maximum-thrust curve of the blade is next plotted and, considering this as a lead curve on a cantilever, the resulting bending moment is obtained. By the usual engineering method of MY/I the fiber stress due to thrust is found and is added algebraically to the fiber stress due to centrifugal force. If the moment of inertia I is taken about the minor axis of each section, a factor of safety is introduced, because the ellipsoid of stress of each section turns about the blade as the radius is increased, so that the thrust does not always act along the minor axis. If the blade is of conventional design and is to run an engine of not less than seven cylinders, and is of the type that is reasonably free from synchronized vibration, nothing else has to be done. However, if the plan form, type of tip, material or construction are changed, the stresses due to torsion and impulses of torque should be investigated.

It is to be noted that the designer of detachable-blade-type propellers does not take into account any deflection or restoring (that is axial component after deflection) component of centrifugal force. In Lieut. Commander Havill's experience, to consider that a component of thrust is counteracted by an axial component of centrifugal force is to neglect an exceedingly large torsion force that results if such a large deflection occurs. The net result is that, in metal, the fiber-stress exceeds the fatigue limit. The metal blade should be designed to withstand all primary stresses without having the fiber stress exceed about nine-tenths of the fatigue strength of the material.

The principle of dynamic rigidity does not seem to be useful in the design of solid aluminum-alloy blades.

With any material, the primary fiber-stresses are calculated by straight forward engineering methods taking into account the centrifugal forces, the bending moment caused by thrust, and torsion. These primary stresses vary proportionately to the square of the tip speeds for geometrically similar propellers of the same pitch. It is erroneous, to copy an existing design of propeller blade and increase its angles without computing the new fiber-stress, because both thrust and torsion increase with increase of pitch. However, as increase of pitch requires more horsepower for the same number of revolutions per minute and for the same airspeed, an empirical formula can be built up which will give an approximate idea of the magnitude of the fiber-stress involved in a given design. For the solid type of metal construction an empirical formula, based on a large number of successful propellers of the detachable-blade type has been devised by Lieut. Commander Havill.

Empirical Formula for Maximum Fiber-Stress—This formula to approximate fiber-stress is as follows:

$$f_t = (RPM)^2 (D)^2 \left(\frac{6D-r}{6D+r}\right) \times \Big(0.00048TB + 0.000000006\,(6D-r)\,HP \left(1.4 - \frac{V}{500}\right) \Big) \qquad (6)$$

f_t = Maximum fiber-stress at r inches of radius, in pounds per square inch

RPM = Revolutions per minute

D = Diameter, in rest

r = Radius, in inches of section under consideration

b = Blade width in inches at radius r, using the unpitched plan form-width

t = Maximum thickness, in inches at radius r

= Density of material in pounds per cubic inch

T = Blade thickness, in inches, at 42-inch radius

B = Maximum blade width, in inches at 42-inch radius

HP = Horsepower per blade, or the total horsepower divided by the number of blades

V = Airspeed in miles per hour and equals zero for static conditions

Equation (6) does not apply very well to a solid one-piece blade made from a single forging from tip to tip, because this type of construction often suffers from fatigue failures caused by synchronized vibrations.

In equation (5), • is the setting angle at the 42-inch station and V is the normal high speed in miles per hour. After the first test, the setting can be varied to give the exact desired number of revolutions per minute.

A one degree change of setting will produce a change of about 60 r.p.m. on direct-drive propellers.

Strength of Propellers.—The strength of propellers is the great problem of the propeller designer. The increase of engine horsepower and engine speeds in the last few years has brought about a condition in which few of the larger engines can be fitted properly with a wooden propeller. The Liberty engine of 400 horsepower at 1,700 r.p.m. imposes a load that approximates the limit of capacity for a wooden propeller while leaving a sufficient factor of safety to meet service requirements. The result has been that the propeller designer was compelled to search for other materials. On account of centrifugal force, the suitability of materials for aircraft propellers is largely dependent on a strength-density ratio in the cases where the blades are solid. It is an advantage to use thin airfoil-sections. The result is that the distribution of the material in the blade is often as important as the amount of material used. Virtually all the propellers now used in both the Army and the Navy are made of aluminum alloy known as 25S special, and sometimes called Standard Steel. They are of solid construction and of the detachable-blade type. The Navy at present is encouraging the development of a chromium-vanadium hollow-steel propeller. One experimental propeller of this type has lately been whirl-tested, and it has more rigidity than has the aluminum-alloy type. This construction will be almost necessary for the greater horsepowers, with which the bending moment caused by thrust is high; in the lower horsepowers it has the advantage of being cheaper, and it probably has longer life than the present type of aluminum-alloy blades.

Metal Propellers.—Aluminum alloy known as 25S special has the following physical properties:

Material: aluminum alloy, known as 25S

Ultimate strength: 55,000 to 60,000 pounds per square inch

Yield point: 30,000 to 40,000 pounds per square inch

Fatigue strength: 12,500 pounds per square inch after heat-treatment and artificial aging

Elongation in two inches: sixteen to 25 per cent

Brinnell hardness: 90 to 125

Modulus of elasticity: 10,000,000 pounds per square inch

Density: 0.101 pound per cubic inch

Specific gravity: 2.79

Grain structure depends mostly on the temperature of the metal as it is poured into the ingot and the rate of cooling the ingot. Ingots are water cooled by a patented process in which means are provided for governing the rate of cooling, and are forged into billets. These are cropped to remove defects and to permit examinations of the grain structure, and are scalped to remove surface defects. They are then forged into propeller blanks. Heat-treating and artificial aging to give the required physical properties are done after the angles are placed on the propeller blank. Bending or twisting the propeller blades without special heat-treatment lowers the fatigue strength to about 11,000 pounds per square inch and, on designs that are close to this fiber-stress, is likely to lead to fatigue failures in from 100 to 200 flying hours.

The Whirl-Test for Strength.—The Navy requires that all basically new designs be given a whirl-test of 100 per cent more than normal horsepower for a period of ten hours without any permanent deformation. During the test the blades are set in pitch with the normal service-setting. It is not sufficient that a design pass the whirl-test; it also should run reasonably smoothly and be free from flutter up to an overload of 25 per cent of horsepower. Flutter is a periodic change of pitch in the blade. Blades that suffer from synchronized vibration usually will flutter at a given number of revolutions per minute during a whirl-test, then run smoothly at some higher speed, only to flutter again violently at some still higher speed. For blades that begin to flutter at a certain number of revolutions per minute after about five hours of test and flutter at all higher speeds, it is assumed that the fiber-stresses are above the fatigue strength of the metal. Thus the actions of the blade during a whirl-test give important information in regard to strength of design.

Necessity for Gearing a Propeller.—Considerations as to the necessity for gearing an aircraft propeller are primarily divided into two classes; first, gearing to reduce tip-speed; second, gearing to enable the propeller to give a higher thrust at low airspeeds, such as will enable a plane to take off with a very heavy load and to have good efficiency at cruising speeds. At the present state of the art, high-power, high-speed engines should be fitted with geared propellers to reduce the high tip-speed that would result if direct drive were used. The amount of gearing should be such as to give a tip speed of about 800 feet per second. Gearing to lower tip-speeds than this usually give no improvement in propulsive efficiency because the increase in diameter requires heavier propellers and increased length of the landing-gear. The result is that the theoretical gains in efficiency are lost. To illustrate this, let us assume that an engine of 600 horsepower at 2,100 r.p.m. is to be used in a new airplane. As a first assumption, let us try to use a two-bladed direct-drive propeller. Then we have:

$$\text{Diameter} = 305 \times \sqrt[4]{\frac{600}{(2{,}100)^2 \times 130}} = 9.755 \text{ feet} \qquad (7)$$

Consequently, we use a propeller nine feet nine inches in diameter, and the tip speed will be 1,072 feet per second. Since V/ND = 0.558, a probably net propulsive efficiency, considering the high tip-speed, of about 74.9 per cent can be expected.

Now consider the case if the engine is geared three to two, which gives the propeller a speed of 1,400 r.p.m. Then we have:

$$\text{Diameter} = 305 \times \sqrt[4]{\frac{600}{(1{,}400)^2 \times 130}} = 11.949 \text{ feet} \qquad (8)$$

A propeller twelve feet in diameter is therefore used and the tip-speed will be 879.6 feet per second. Since V/ND = 0.681, a probably net propulsive efficiency of about 78.6 can be expected.

Before a decision can be reached, it must be determined whether a propeller twelve feet in diameter can be used. If ground clearance is insufficient, the landing-gear must be lowered, with its resultant increase in drag of the plane. If installed on a twin-engine type of plane, the twelve-foot propeller probably would require a re-spacing of engines which would result in practically a redesign and an increase of weight. If the landing-gear has to be lowered and the increase in drag is more than the 3.7 per cent gain in efficiency, then it is better not to gear.

Let us assume that the two-bladed twelve-foot diameter propeller is impractical; so a three-bladed propeller will be tried. Direct drive for this would require a diameter of

$$\text{Diameter} = 285 \times \sqrt[4]{\frac{6{,}000}{(2{,}100)^2 \times 130}} = 9.115 \text{ feet} \qquad (9)$$

Therefore a propeller nine feet in diameter would be used, and the tip-speed would be 989.6 feet per second. Since $V/ND = 0.605$, a probable net propulsive efficiency of 74.5 can be expected. It should be noted that, for the same values of V/ND and the same tip-speeds, three-bladed propellers are about two per cent less efficient than two-bladed propellers.

The reduction in tip-speed of this three-bladed propeller, compared with the two-bladed direct-drive, together with the increase in (V/ND), causes it to give approximately the same propulsive efficiency. In addition, the three-bladed type should give a better take-off in this case. Thus this particular plane probably would be fitted with a three-bladed direct-drive propeller as the best engineering compromise. Lieut Commander Havill says that there is no set rule about gearing; each case must be solved on its own merits. However, if gearing is resorted to, a reduction of tip-speed below 800 feet per second seldom pays in heavier-than-air types of craft. As engine horsepowers and engine speeds are increased, gearing will become more and more prevalent.

Variable-Pitch Propellers.—It is well known that a fixed-pitch propeller can give the best results only under a given set of conditions. As stated previously, the pitch setting that is best for take-off and climb cannot be the best for top speed or for cruising speeds. Fixed-pitch designs or types that are adjustable in pitch on the ground are in fact a compromise between characteristics desired and characteristics obtainable. Under one set of conditions the propeller efficiency may be the maximum possible, but under every other condition the efficiency is somewhat less. The subject of variable-pitch propellers the effective pitch of which can be changed while the airplane is in the air has interested aeronautical engineers ever since the basic principles of air propellers were understood. Numerous patents have been granted as a result of attempts to evolve a serviceable mechanism of this kind. The patents include ideas not only for changing the effective pitch but also for varying the diameter and the surface area of the blades. It must be understood that the variation of effective pitch provides only part of the possible theoretical increase in efficiency that can be realized; however, the mechanical difficulties in the way of changing the diameter and area of the blade have so far prevented

any encouragement in this matter. It seems that the ability to change the effective pitch of the blades offers the best field for development, and tremendous effort has been concentrated on this feature.

Advantages of Variable Pitch—The advantages of a variable-pitch propeller as stated by Lieut. Commander Havill are as follows:

(1) *For Heavy Patrol Planes.*—A low pitch during take-off and a higher pitch during cruising could be used. Instead of cruising with the engine throttled, it seems better to let the engine operate at full throttle and to reduce the number of revolutions per minute by increasing the pitch. This case would fit exactly the service of air-mail planes, where the advantages of heavy-load take-off and of fuel economy at cruising speeds could be obtained with the same propeller.

(2) *For High-Altitude Fighting Planes Equipped with Supercharged Engines.*—With a conventional fixed-pitch propeller, it is impossible to make use of the full power of the supercharged engine at any great altitude without using an excessively high number of revolutions per minute. The practice of taking-off and climbing to about 6,000-feet altitude with the engine partly throttled is the only partial solution of the problem when a fixed-pitch propeller is used.

(3) *To Reduce the Length of Run after Landing.*—In the case of complete reversal, the negative thrust could be used to act as a brake after landing; however, I believe that the installation of mechanical brakes promises to eliminate the necessity for this feature.

Some fairly successful variable-pitch propellers are now available, but the development is not such as to make them of general service use. The difficulties are, primarily, that in the higher horsepowers, say above about 185 horsepower, the propellers become very "rough" after about 40 to 50 flying hours. The high value of the centrifugal force on each blade under a normal number of revolutions per minute presents a bearing problem rather than actuating-mechanism problem. Simply to take on a four-inch-diameter roller bearing or ball bearing, the total centrifugal-force load which is about 50,000 pounds, places such a load on the pitch actuating mechanism that the small parts wear sufficiently within a short time so that both blades do not have the same effective pitch. This inaccuracy causes a difference in thrust between the blades that results in violent vibrations.

In Europe, a type of variable-pitch propeller that uses oil pressure to counteract the bearing load has met with some success in the lower horsepowers; and at present the Navy is experimenting with a type that counteracts the bearing load with the hydrostatic pressure produced by a revolving column of mercury.

In the high-speed fighting-type of airplane, the weight of the variable-pitch propeller is important because, beyond a certain weight, better results could be obtained by putting the extra weight into a larger and more powerful engine and using a fixed-pitch propeller. Such a high restriction as to weight of the propeller does not apply equally to the large heavy patrol plane, because the propeller constitutes such a small percentage of the total load that the climb and take-off are not so much affected.

Value of Reduction Gearing.—The table on page 1691 gives the performance tests of a U. S. Government transport airplane equipped with a 400-horsepower direct-drive engine and the same engine fitted with a two to one reduction gear. It can be seen that climb near the ground has been increased from 280 to 618 feet per minute by substitution of the geared engine. It will be noted that an increase in high speed, as well as a considerable increase in service ceiling, has also resulted from the use of the low-speed propeller. Besides the increase in thrust available through improved propeller efficiency, the low-speed propeller also allows a greater cruising range. With the same thermal efficiency of the engine, decreased fuel consumption for any given propeller thrust is obtained because of the greater efficiency of the low-speed propeller. Ability of the airplane to take off with high power loadings combined with improved fuel consumption for a given thrust horsepower makes the low-speed propeller type of engine a logical solution for long distance cruising.

The difference in propeller efficiency in an airplane designed for 120 miles per hour with a 150 horsepower engine, at 1,000 r.p.m. and at 1,800 r.p.m., was determined analytically by the usual formulae and is given in the accompanying diagram at Fig. 807 The curves show propeller efficiency only in level flight. The difference of efficiency between high and low speed of rotation becomes greater during climb and take-off. These curves do not take into consideration the effect upon propeller efficiency of the fuselage nose or the obstructions immediately behind the propeller. Nor do they consider the increased drag of the airplane with the high-speed propeller, which is caused by the higher slipstream velocities. The actual results of the official performance tests of a U. S. Government transport airplane given in the accompanying table shows more clearly than any detailed calculations the effect of low propeller speed upon the performance of a transport airplane.

It is significant that the new Curtiss Condor bomber, which has shown excellent performance, mounts geared engines. The Navy has long been using geared engines in its PN10 flying boats.

The advantage of the large-diameter slow-turning propeller in giving a shorter length of run for take-off and an improved rate of climb is too great, particularly for heavily loaded commercial planes, to be neglected. Gearing now seems to be the only solution with conventional engines but gears on such high-powered engines are a mechanical problem that, up to the present time, has not been solved in an entirely satisfactory manner, though various designs have been made that give excellent results in practice.

Airplane Propeller Drive Gears.—Airplane propellers, as the writer has previously mentioned operate most efficiently at a speed range of from 1,200 to 1,500 r.p.m. In this speed range it is possible to obtain a large enough propeller diameter to avoid excessive interference between the propeller slipstream and the fuselage and other parts back of the propeller. The most efficient pitch also can be obtained in this speed range. At higher speeds it is necessary to restrict the propeller diameter in order to avoid setting up excessive strains in the propeller due to too high circumferential speed. The most efficient speed of the average modern water-cooled airplane engine, is usually in the range from 1,800 r.p.m. to 2,200 r.p.m.

It readily will be seen that a reduction gearing of some sort is desirable, in order to allow both engine and propeller to operate at their best speeds.

In considering a suitable reduction gear for the aviation engine, two important factors enter into the design:

First, the greatest possible efficiency must be realized.

Second, the construction must be light and compact, although at first thought a heavy and bulky construction would appear necessary to withstand the internal stresses created in the transmission of so much power as is developed by the usual large engine.

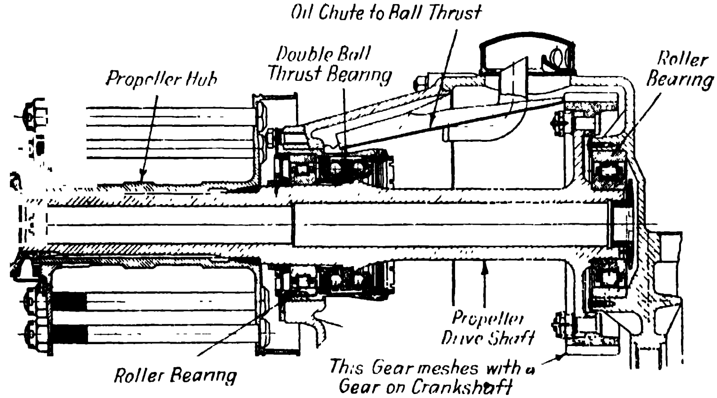


Fig. 808.—Simple Reduction Gear Used for Propeller Drive on Napier "Lion" Aero Engines.

In a preceding chapter on water-cooled aeronautical motors, the simple and effective reduction gear used on Packard aeronautical engines was shown as applied to the 2A 2,500 engine. In this the reduction was obtained by a single pair of spur gears, one mounted on the propeller shaft between large anti-friction bearings was meshed with a smaller gear carried by the engine crankshaft below it, this also being supported by anti-friction bearings at each side. The gears are of heat-treated, high strength alloy steel and have exceptionally wide faces to transmit the great horsepower produced by that engine. The simple and effective reduction gear used on Napier Lion engines is shown at Fig. 808. A spur gear on the propeller shaft, which rotates in roller bearings and which is provided with a double ball thrust, is meshed with a gear on the engine shaft, not shown in the illustration.

Rolls-Royce Gear.—There are other forms of reduction gears besides that shown at Fig. 808. Rolls-Royce, Ltd. of Derby, England, have been building for some time past a reduction gear of the epicyclic type for use with their twelve-cylinder aircraft engine, and have been very successful with this gear. This is clearly shown at Fig. 809 and it will be evident that it results in a much neater nose assembly than is possible with the superposed spur gear reduction previously considered. In considering the

design of the reduction gear for the Rolls-Royce engine, full attention was given to various types of gears including almost every type which could be considered at all practicable, and the decision was reached that the epicyclic gear gave the best combination of strength, wearing qualities and other desirable features, without too great loss of efficiency.

The form in which only two gears is used is most efficient mechanically, but it cannot be made as compact about the center line and the stress of power transmission produces a strain on relatively few teeth, which must be large to resist it adequately, and of course, considerable tooth friction is present because of high unit pressures. Unit pressures are lower in epicyclic gears because more teeth are in engagement. The factor of bearing friction between the planets and their pins is reduced by using anti-friction bearings. Epicyclic gears are best for high powers.

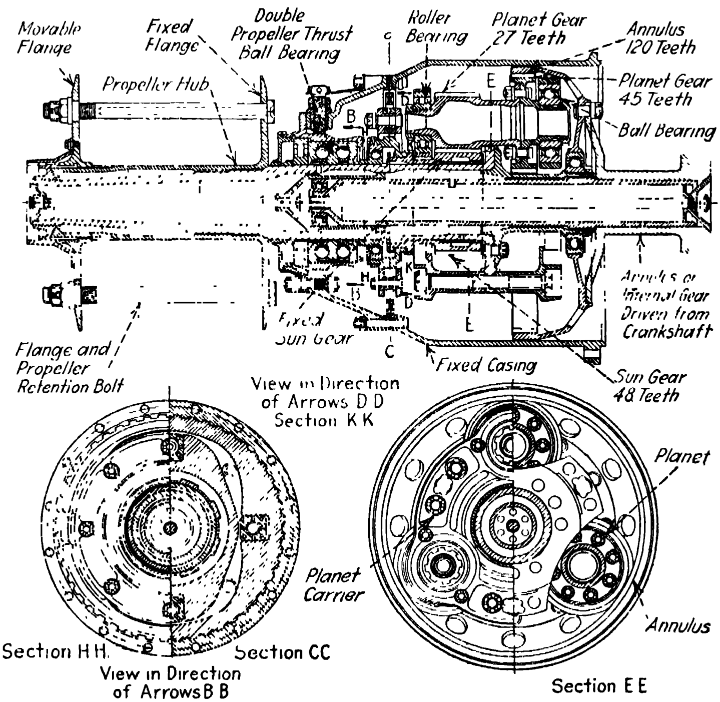


Fig. 809.—Diagrams Showing Rolls-Royce Epicyclic Speed Reducing and Propeller Drive Gearing.

Various methods of compounding plain epicyclic gears have been tried, but the best type is undoubtedly that combining double planets, an annulus driven from the crankshaft, and a sun fixed to the engine casing. One of the great advantages of this type of gear is that the planets are not held on overhanging pins as is the case with plain planets, but are balanced about the flange on the propeller shaft in such a way that the projecting portions of this flange, to which the two halves of the planet cage are bolted,

are not put in torsion by the driving load on the planets.

When a simple spur gear reduction is used on a large engine, some form of shock absorbing spring drive is needed to reduce shocks in power transmission.

Lorraine Planetary Gear.—A reducing gear of the planetary type for aircraft engines has been developed by the Société Lorraine of Argenteuil, France, and in addition to being used on the aircraft engines of that company is also fitted by the Armstrong-Siddeley Co. in England. A sectional view of the Lorraine reducing gear is shown at Fig. 810. The propeller-carrying shaft is supported at the forward end by a roller bearing O and at the rear by another roller bearing P and a bronze bushing K fitted inside the crankshaft. The front journal of the crankshaft is supported in a babbitt-lined bearing. To an integral flange on the crankshaft is bolted the internal gear crown C. This gear crown, in rotating with the crankshaft, carries along the propeller, by meshing with the planetary pinions D, which rotate both around their own axes and around the stationary pinion I, which latter is secured to the housing by bolts i. The propeller-carrying shaft, which carries the planetary pinions, D, turns at a lower speed than the crankshaft, the reduction ratio being 1.545 :1.

Lubrication of the reduction gear is effected by means of oil under pressure which enters the interior of the hollow propeller-carrying shaft through holes T and U. This oil also lubricates the front bearing S of the crankshaft and the inside bearing K through the same holes T and U. Passing through oil grooves cut in the bearing bushing it floods the roller P, whence it is thrown off into the collector channel M formed near the periphery of the pinion-carrier plate H. Centrifugal force compels the oil to enter the hollow pins F on which the planetaries revolve, through registering drill holes. From the interior of these pins it passes through radial holes to the rollers on which the planetaries revolve, and it escapes from the roller bearings through radial holes, V drilled in the pinions. Thus there is a constant circulation of oil, which serves not only to lubricate but also to cool the pinions. The oil thrown off by the pinions gathers on the walls of the housing and some of it collects in a small pocket N, whence it flows through a passage N to the roller bearing O and the double thrust bearing J which takes the propeller thrust. The lower part of the housing for the reducing gear is filled with oil to such a level that the internal gear crown is at all times partly submerged. Thus the meshing gears are constantly flooded with oil. An oil-guard Q at the side of the reducing gear toward the propeller prevents loss of oil from the case. The reduction ratio of 1.545 1 was adopted with a view of limiting the speed of the engine to a value which would assure a satisfactory life of the engine and to keeping the propeller diameter down to a figure which would not be prohibitive on multi-engined airplanes and seaplanes. An engine speed of 1,900 r.p.m. corresponds to a propeller speed of 1,230 r.p.m. The pinions and gears of the reducing gear all have straight teeth and are mounted on parallel axes. They have such dimensions that their accuracy may be readily checked by the usual inspection previous to assembly. The clearance between teeth is determined by the manufacturing process and no adjustment is necessary in order to insure proper distribution of loads. The tooth loads and bearing loads are quite moderate.

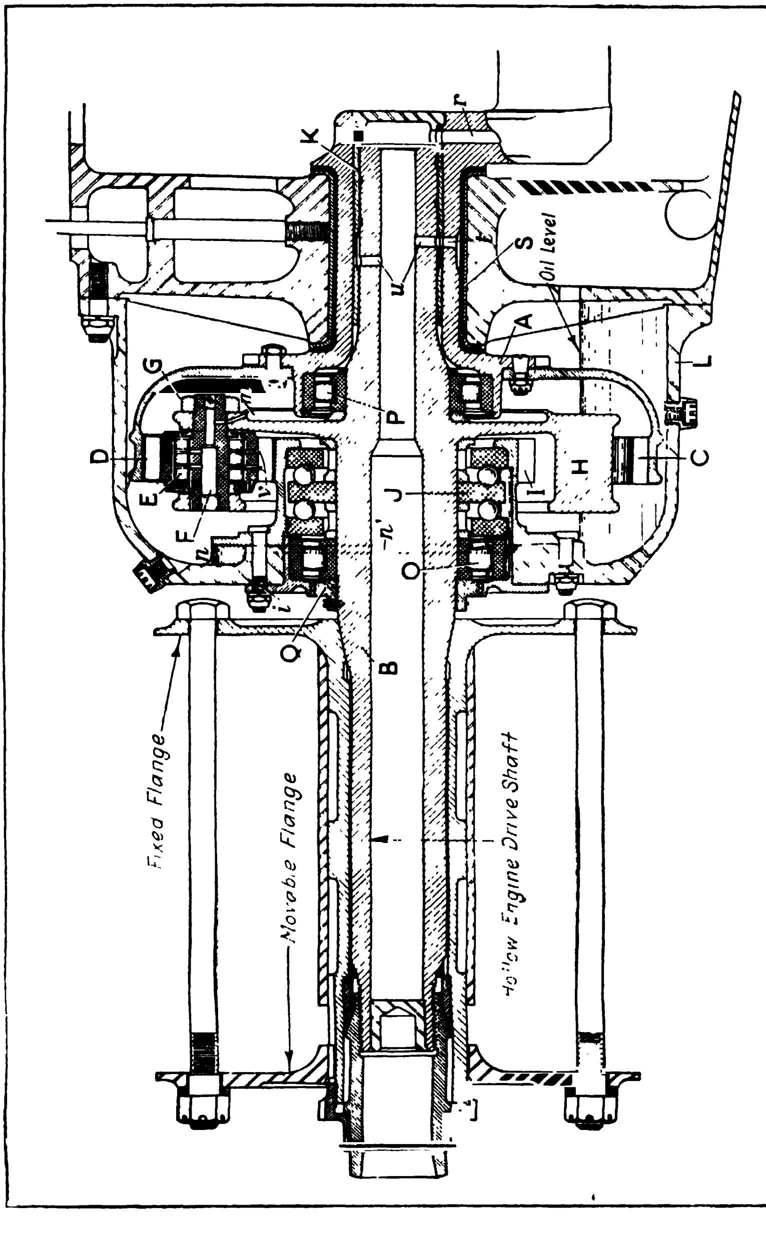


Fig. 810.—Sectional Diagram Showing Construction of Lorraine Epicyclic Speed Reducing and Propeller Drive Gear.

The low-speed shaft which forms the cage of the planetary gears is a very robust member as can be seen by referring to the illustration at Fig. 811 which shows the important parts and it is made in a single piece, and therefore not subject to deformation. Studs for the planetary pinions are straddle-mounted. These studs are located at equal angular distances from each other and at equal distances from the axis of the shaft by mechanical

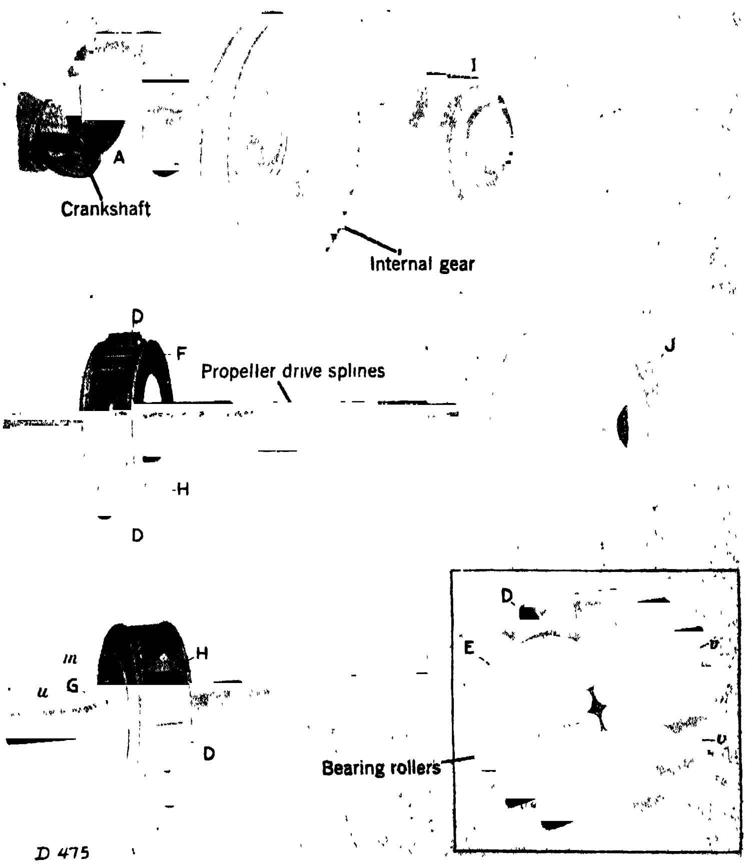


Fig. 811.—Illustrations Showing Parts of the Lorraine Reduction Gear Shown at Fig. 810.

means in such a manner that their angular spacing and their concentricity can be readily checked. The positioning of the pinion studs is not affected by wear, hence the studs and the pinions can be replaced at any time without need of highly specialized labor. The wearing parts are constituted by roller bearings at which there is only an insignificant amount of wear. Replacement of these bearings is an easy matter and does not call for any adjusting operations, properly speaking. All parts are mounted concentric with respect to the crankshaft, which makes it possible to assure

one's self of the proper operation of the assembly before placing it in service.

Reduction and Reverse Gears.—Reverse gears are not used in airplanes but are desirable in lighter-than-air craft because a reverse motion of the propellers will sometimes aid in maneuvering an airship. The speed reducing and reverse gears of the U. S. S. "Shenandoah" are shown at Fig. 812. A special clutch of the multiple disc or plate type is installed in the transmission line between the engines and the gearing, this making it possible to stop the propeller while the engine continues to run, just as it does in a motor boat or an automobile. A braking device is provided which permits the engineer to arrest the motion of the propeller at any desired point as it is sometimes needful to have the airscrew stop in a horizontal instead of a vertical position to obtain full ground clearance. All gearing is of the planetary or epicyclic type and all gears employed to give reduced speed or reverse motion are in constant mesh. A sliding dog clutch actuated by a shifter lever connects the power shaft to either set of gears as desired. The master clutch must be fully released before the positive clutch is shifted to engage either set of gears.

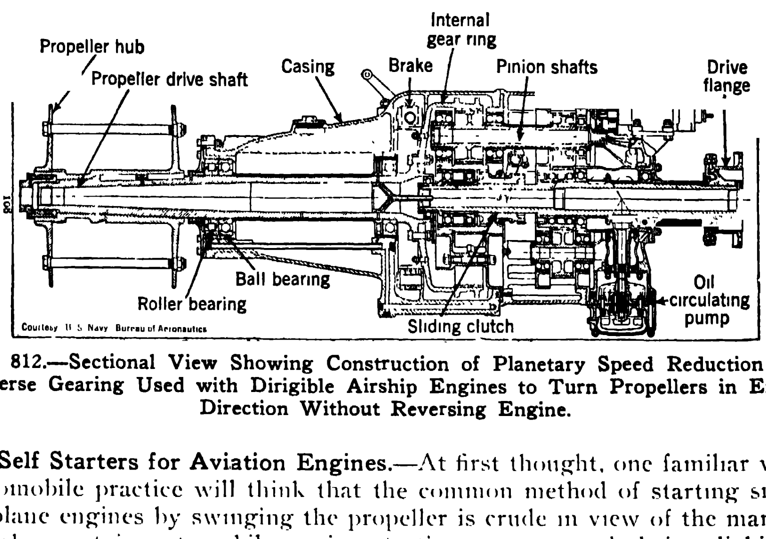


Fig. 812.—Sectional View Showing Construction of Planetary Speed Reduction and Reverse Gearing Used with Dirigible Airship Engines to Turn Propellers in Either Direction Without Reversing Engine.

Self Starters for Aviation Engines.—At first thought, one familiar with automobile practice will think that the common method of starting small airplane engines by swinging the propeller is crude in view of the marked development in automobile engine starting systems and their reliability, which would indicate that modifications should be designed for use with aircraft motors. Leading authorities in the aeronautical industry are favoring the fitting of reliable and easily operated starters especially on commercial machines. Commenting editorially on this subject, *Aviation* Magazine says:

"Undoubtedly one of the greatest factors in the popularizing of automobiles was the introduction of the self starter. Cranking was a nuisance and dangerous even for strong men, and it practically eliminated women from the driving. If self starters made a difference in the popularity of automobiles they certainly will make a much greater difference with airplanes and their high powered engines. Swinging a prop by hand is hard work; requires

considerable skill, and, to put it mildly, is not a pastime in which most of us like to indulge. At present, hand cranks are fitted to most of the new commercial engines but if airplanes are to be handled by women and amateurs they should have every convenience, and self starters which are as easy to operate as those on automobiles will be required. The starter should certainly be workable from the cabin for otherwise it really takes two people to start the plane. The unfortunate part is that the planes which amateurs fly are usually of small size and in such planes every ounce of weight counts and to date most of the starter development has been done for larger engines and especially the really large ones which are nearly impossible to start by hand. The progressive manufacturer of small engines would be making a great step forward if he should fit all his engines with self starters. This would give the starter manufacturer a real basis upon which to start development and production, and it would not be a long while before all buyers of engines demanded that self starters be fitted as regular equipment."

Engine Starting Methods.—Various forms of starter have been tried for years with but indifferent results and, so long as the engines were small and were capable of being cranked by hand by pulling through the propeller, starters were not received with much favor. Pulling through the propeller by hand as previously shown is a dangerous operation at best and even a skilled mechanic of good physique cannot turn the engine past more than one or two compression points, except in the case of small engines having no military and very little commercial value. Electric starters have been devised which employ a small motor, driving through a large gear-reduction. The early forms of these starters gave trouble and they were very hard on batteries; also, the battery capacity required entailed the use of large and correspondingly heavy batteries. Therefore, for many years after the World War, engines up to and including the 200 horsepower size were started by pulling the propellers when the propeller was accessible. For larger engines and for seaplane work, small hand-starters were used which consisted solely of a hand-crank geared down to the crankshaft in connection with a booster magneto.

Compressed-air starters of various types came into extensive use on European engines and were used to some extent on early American engines. These starters consisted of a supply of compressed air stored usually in a small steel bottle that was carried on the airplane, a miniature carburetor in the air-supply line, a distributor driven from a camshaft, and individual pipes leading to check-valves installed in the cylinders. These compressed-air starters have been very efficient so far as starting is concerned but, in this country, airplane engine builders have been unwilling to accept the multiplicity of piping and valves required and the driving of any unnecessary mechanism from the camshaft.

U. S. Navy Practice.—Starter developments in the United States have taken the form of the inertia starter, said Lieutenant C. E. Champion, Jr. U. S. N., in a paper read before the Buffalo Section, S. A. E. recently. These are being built for the Navy at present by the Healy-Aeromarine Bus Co., successor to the Aeromarine Plane & Motor Co., and by the Eclipse Machine Co., in its plant at Hoboken, N. J. These starters employ a hand-

crank and a gear-train which drives a miniature flywheel, and a constant-torque slipping-clutch through which the flywheel can transmit its energy to the engine. In operation, the crank is turned by hand until the flywheel is brought up to the required number of revolutions per minute. A man of normal physique should accomplish this in 20 to 30 seconds. The gear-reduction is approximately 150 to 1 and the weight of the flywheel

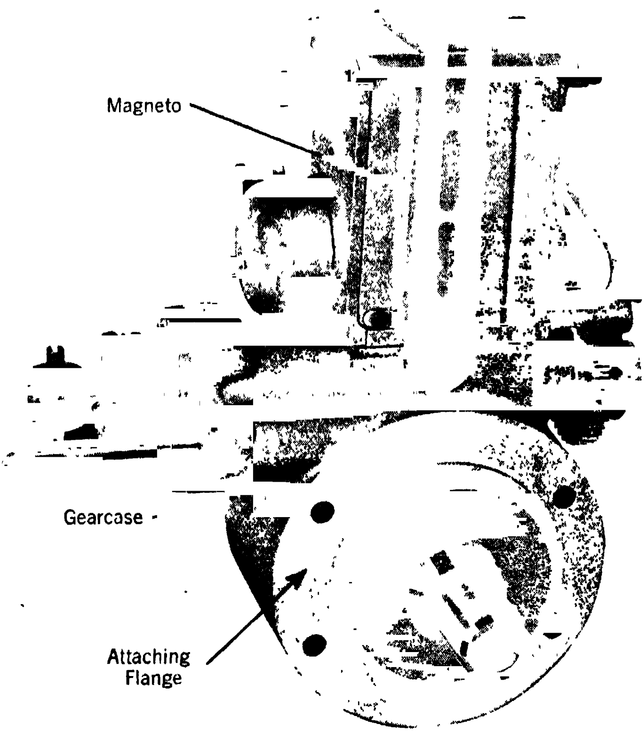


Fig. 813.—Wright Hand Turning Gear and Starting Magneto.

is about four pounds. When the flywheel has been brought up to about 15,000 r.p.m., a tripping device connects the flywheel, through the same gear-train used to drive it, to the constant-torque clutch and, at the same time, engages the starting-dog. At average operating-speeds, the energy stored-up in the flywheel amounts to 5,000 foot-pounds or more. The clutch can be set for any desired break-away torque. In small engines, a torque of 400 foot-pounds suffices but, for the largest engines, clutches are set for 750 foot-pounds.

By careful arrangement of the gear-train, these concentric starters have been reduced in size to that of the crown of a man's hat and their total weight is between 19 and 25 pounds depending on the model. They are

very rugged and reliable. Incidentally, it is indicated that their use will eliminate the necessity for the hand-operated booster-magneto used for starting purposes, which will result in a saving of some eleven or twelve pounds in weight.

Electric Starters.—Starters utilizing electric motors to turn over the engine have been recently developed, and when properly made and maintained in an efficient condition they answer all the requirements of an ideal starting device. The capacity is very high, as the motor may draw current

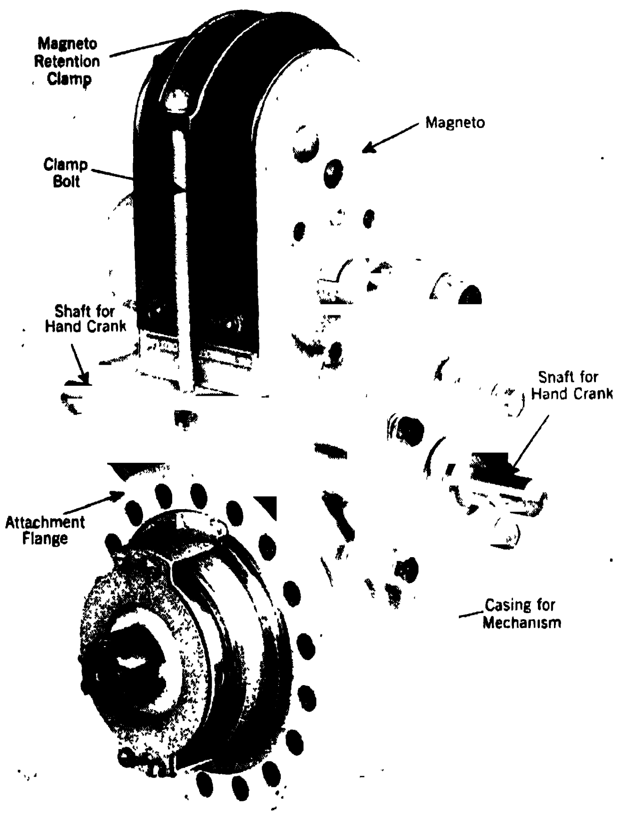


Fig. 814.—Eclipse Aviation Hand Starter with Booster Magneto Integrally Mounted.

from a storage battery and keep the engine turning over for considerable time on a charge. The objection against their use is that it requires considerable weighty, complicated and costly apparatus which requires the services of an expert electrician to repair should it get out of order, though if battery ignition is used the generator takes the place of the usual ignition magneto and some saving in weight is effected. The fundamental units of a self-starting system, therefore, are a generator to produce the electricity, a storage battery to serve as a reservoir, and an electric motor to rotate

the motor crankshaft. Generators are usually driven by enclosed gearing, though silent chains are used where the center distance between the motor shaft and generator shaft is too great for the gears. An electric starter may be directly connected to the gasoline engine, as is the case where the motor bolts to a flange. The motor may also drive the engine by means of a direct gear reduction, the Bendix pinion shift being used to engage a starter gear ring attached to the propeller flange.

Every electric starter must use a switch of some kind for starting purposes and most systems include an output regulator and a reverse current cut-out. The output regulator is a simple device that regulates the strength of the generator current that is supplied the storage battery. A reverse current cut-out is a form of electrical check valve that prevents the storage battery from discharging through the generator.

The Wright Starter.—The Wright Hand Turning Gear was the successful result of several years of work in the development of a device by which an aviation engine may be started readily by hand, without danger of injury to the operator or damage to the engine or starter. The gear was simple, compact, and reasonable in weight, and was used on engines of widely different sizes without any change other than a simple adjustment. It was supplied in two gear ratios, six to one or fifteen to one, specified by the customer. In the illustration at Fig. 813, which shows the side of the starter toward the engine, most of the external parts of the gear are visible. The splined shaft fits into the rear end of the engine crankshaft and five holes receive five studs by which the gear is bolted to the rear end of the crankcase. The bolting flange and spline are designed to fit the standard Army and Navy starter mounting as used on Liberty, Wright, Curtiss and other engines. The starter shaft carries a bronze worm wheel, which engages a worm driven by the handcrank. The starting magneto, which is an integral part of the device, is also driven by the starting crank, through gears.

In starting, the worm is brought into contact with the worm wheel by pushing on the small rod beside the starting crankshaft. Turning the crank then brings the worm into full engagement, and further turning rotates the engine crankshaft. When the engine fires, the worm is thrown out of engagement, but as it slides endwise on its shaft no end motion is transmitted to the starting crank. The disengagement of the worm, however, does not throw the starting magneto out of gear, so that it may be kept in operation by turning the hand crank until the engine has picked up enough speed to fire regularly on the running magnetos. The starting magneto furnishes high tension current which is distributed to the spark plugs through one of the main magnetos. It is designed to operate in connection with a "trailing brush" on the running magneto, which gives a greatly retarded spark, thus reducing to a minimum the probability of the engine "kicking back." However, should a "back-kick" occur while the engine is being cranked, the engine and starter are positively protected aginst damage by a multiple disc friction clutch, interposed between the worm wheel and the splined shaft, loaded by four carefully equalized springs. Thus a "kick back" results merely in slipping this clutch. An external ratchet on the starting crankshaft positively prevents the crank from turning backwards. The only adjustment required is for spring ten-

sion of the friction clutch. This adjustment is made at the factory to suit the particular engine with which the turning gear is to be used, and ordinarily does not require further adjustment in service. Thus the gear requires no attention or adjustment after installation on the engine.

The addition of the turning gear increases the length of the engine by 4⅛ inches, and a space of 4⅞ inches is necessary to remove it without disturbing the engine. The weight of the gear, including the magneto but not the hand crank, is 25 pounds. The starting magneto is attached to the gear by a special strap which permits its removal without the use of wrenches, a feature of great advantage in working in the space between the engine and the fire-wall. The crank may be attached to either end of the worm shaft, and the gear as a whole may be mounted in several different angular positions. With an adapter plate between the gear and the engine, any desired angle between the starting crank and the horizontal may be obtained. The starting crank is made up with a long shank and is supplied with the end fittings not attached, so that it may be cut to the length best suited to the airplane in which it is used.

The gear ratio between the hand crank and engine crankshaft is such that under ordinary conditions one man can turn the engine, unless the location of the crank with respect to other parts of the airplane is such as to prevent him from exerting his strength effectively. To meet unfavorable conditions, the grip on the crank has been made long enough to allow for cranking by two men. The hand crank is usually pinned permanently to the starter shaft, so that it may be carried in position, but if desired, the end of the crank may be fitted with a slot to allow it to be removed. Ball bearings on the spline shaft and on the worm shaft take the thrusts of the worm and gear. All parts are thoroughly lubricated by pressure feed from the engine oiling system.

Eclipse Aviation Engine Starters.—The Eclipse aviation hand starter with booster magneto is shown at Fig. 814. The gear ratio is twenty to one for engines up to 2,000 cubic inches displacement, twelve to one for engines up to 1,400 cubic inches and six to one for engines up to 900 cubic inches displacement. It may be applied to any aviation engine having a standard attachment plate. It has been fitted to the Liberty, Wright, Curtiss and other types of engines. The weight complete with brackets, booster magneto and integral gearing is 28 pounds. The starter may be had without magneto if desired.

The hand starter consists of a gear reduction operating an automatic meshing and demeshing mechanism through an adjustable multiple disc clutch, operating in grease. The purpose of the multiple disc clutch is to provide a disconnection in the drive in case of engine backfire. Means are provided for preventing backward rotation of the handcrank at backfire, thus preventing any possibility of injuring the operator. The automatic shift mechanism, as well as the backfire clutch are absolutely identical with the mechanism used in the Eclipse Aviation Electric Starter. The complete hand starter weighs seventeen pounds.

Provision has been made to permit cranking from either side of the plane desired. A sufficient number of holes has been located in the mounting flange to permit a varied amount of angularity of the hand crankshaft,

in order to place the hand crank in the most accessible position when applying the starter to the ship. Where hand magneto is desired, an attachment consisting of gearing, magneto bracket and hand magneto complete can be furnished for adapting to the standard hand starter. The advantage of this attachment lies in the fact that under normal conditions an operator cranking the hand starter at approximately 80 r.p.m. to the crank handle shaft will spin the magneto armature at approximately 1,000 r.p.m. The gear train transmitting rotation from the hand starter shaft to magneto armature is completely enclosed against entrance of dust.

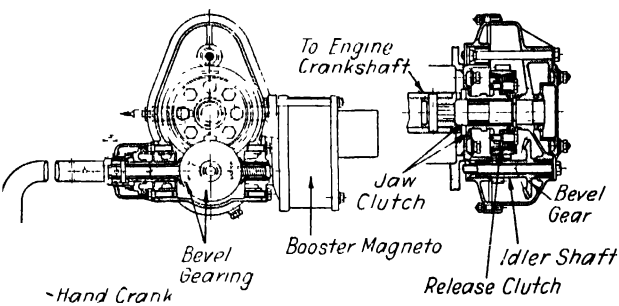


Fig. 815.—Sectional Views of BMW Hand Starter Gear Showing Construction of Devices of this Character.

BMW Hand Starting Gear.—The sectional view at Fig. 815 shows the BMW (German) hand starting gear for large engines and brings out the details of construction of such devices. The engine is revolved by a hand crank through the medium of bevel and spur reduction gearing. There is a bevel pinion on the hand crank operated shaft, this meshing with a bevel gear mounted on an idler or intermediate shaft which drives a spur pinion. This in turn engages with a spur gear cut integrally into the outer periphery of a double cone safety drive clutch member. The male portions of the drive are attached to the dog clutch that engages the corresponding member on the engine shaft. The bevel intermediate gear also drives the booster magneto shaft through a pinion at a considerably higher speed than the engine shaft is driven because of step up gearing in the magneto. There are two speed reductions between the hand crank and engine crankshaft, one between the bevel pinion and the gear it drives, the other between the spur pinion on the intermediate shaft and the spur gear on the safety drive clutch. If the engine should back fire, not only is the jaw clutch disengaged because of the tapering faces of the co-acting faces but the safety clutch also slips. All mechanism is enclosed in a dust proof casing.

Large engines are often started by using the propeller or a hand turning gear to put one or more of the cylinders at compression, depending upon the number of cylinders and then using a small booster magneto, somewhat like the old time telephone magneto only it is capable of generating high

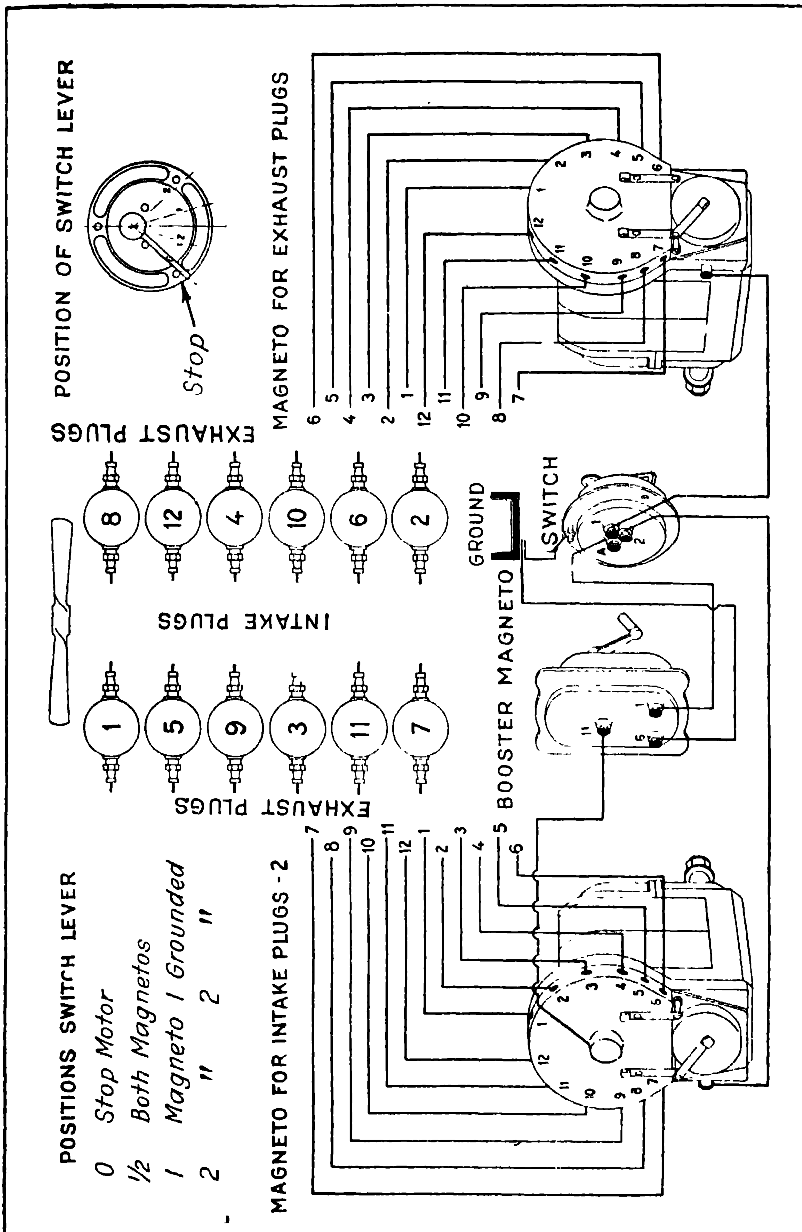


Fig. 816.—Wiring Diagram Showing Installation of "Booster" Type Magneto on Fiat Aviation Engines.

tension spark and so wiring it to the switch that with the ignition switch on, briskly turning the small hand crank (the booster being placed on the instrument board or other convenient place in the pilot's cockpit) will send a secondary impulse, via the distributor of one of the big magnetos to the sparkplugs in the cylinder holding compressed gas and starting the engine. Starting is not as positive by this system. A typical wiring diagram for Fiat A20 engine is shown at Fig. 816.

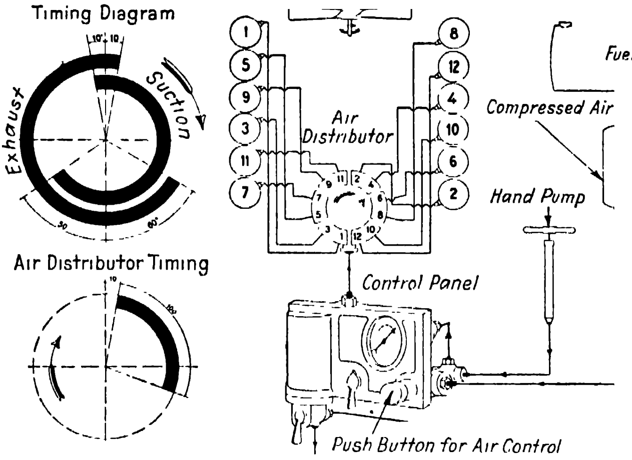


Fig. 817.—Piping Diagram for Compressed Air Starter Used with Fiat Aviation Engines.

The Fiat Air Starter.—As an example of a foreign development of an efficient air starting system, the writer presents that used on Fiat twelve-cylinder Vee engines previously described. The piping scheme is shown at Fig. 817. It consists of an engine driven air distributor timed in proper relation to the valve timing, the distributor being connected to the cylinder check valves by flexible tubing. A control panel, as shown in section at Fig. 818, combines a small priming tank which holds a quantity of fuel sufficient for several starts. The main air supply is carried in an air tank and compressed air may be obtained from a hand pump or from a small engine driven air pump or air bottles may be used. As will be seen from sectional view of control panel, small check valves permit air to go to air tank from either motor air pump or hand pump. When the air valve button is depressed to open the main air valve, the compressed air under pressure flows from the tank through the control panel, picking up some priming fuel on its way, then to the distributor to the cylinders in their proper firing order. The compressed air moves the pistons down, the fuel charged mixture fires just as gas from the carburetor would and the engine picks up its cycle. The grouping of the priming tank and fuel control cocks with the air valve and pressure gauge in one neat panel greatly simplifies the assembly.

Early Air Starting System.—The "Christensen" air starting system which was one of the pioneer forms which has been used in airships in the original or modified form is shown at Fig. 819. An air pump is driven by the engine, and this supplies air to an air reservoir or container attached to the fuselage. This container communicates with the top of an air distributor when a suitable control valve is open. An air pressure gauge is provided to enable one to ascertain the air pressure available. The top of each cylinder is provided with a check valve, through which air can flow only in one direction, i.e., from the tank to the interior of the cylinder. Under explosive

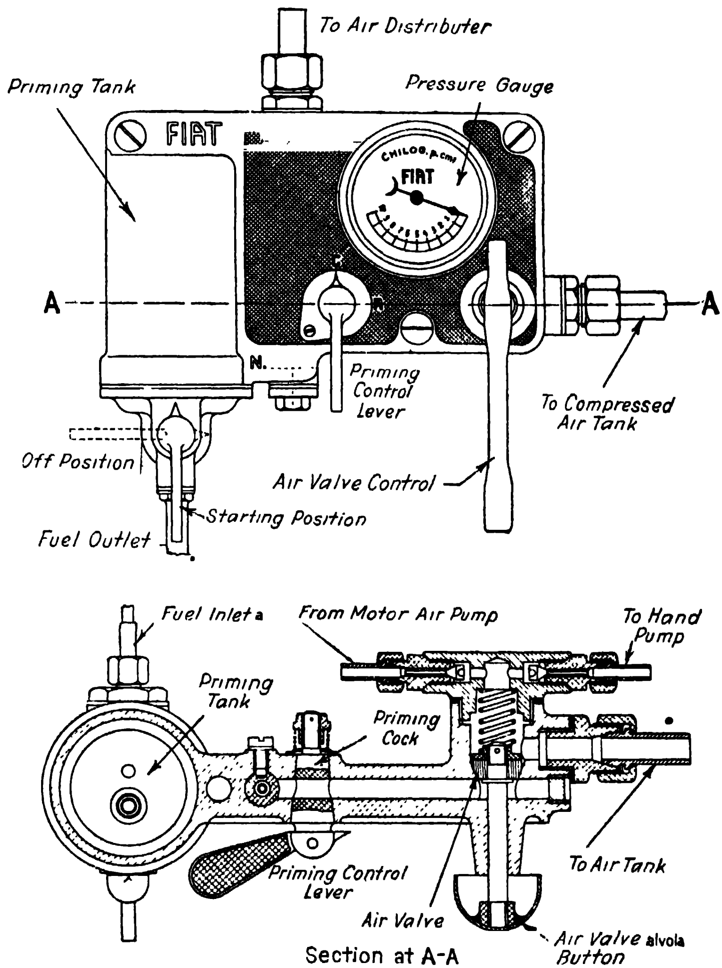


Fig. 818.—Diagrams Showing Construction of Fiat Air Starter Control Panel which Incorporates Priming Tank and Control Valves and Pressure Gauge.

pressure these check valves close. The function of the distributor is practically the same as that of an ignition timer, its purpose being to distribute the air to the cylinders of the engine only in the proper firing order. All the while that the engine is running and the car is in motion the air pump is functioning, unless thrown out of action by an easily manipulated automatic control. When it is desired to start the engine a starting valve is opened which permits the air to flow to the top of the distributor, and then

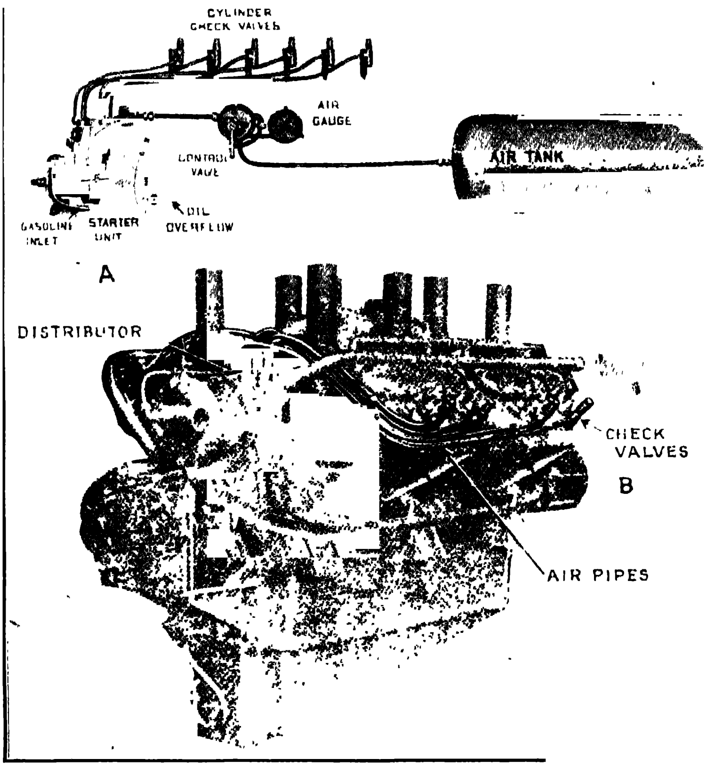


Fig. 819.—Parts of the Christensen, a Pioneer Air Starting System Shown at A and Application of this Early System to an Eight-Cylinder "Vee" Type Motor at B Showing Check Valves and Piping.

through a pipe to the check valve on top of the cylinder about to explode. As the air is going through under considerable pressure it will move the piston down just as the explosion would, and start the engine rotating. The inside of the distributor rotates and directs a charge of air to the cylinder next to fire. In this way the engine is given a number of revolutions, and finally a charge of gas will be ignited and the engine start off on its cycle of operation. The parts shown at A are for a six-cylinder engine, the installation at B shows the method of mounting the air distributor and the piping leading to the check valves in an eight-cylinder Vee engine.

The Heywood Injection Air Starter.—One of the latest aircraft accessories on the market to make aviation safe and to carry to the plane a modern degree of convenience is the Heywood High Pressure Injection starter manufactured by the Heywood Starter Corporation, Detroit, Michigan. The Heywood starter is for use on engines in airships, seaplanes or land planes and large trucks, tractors and busses. A number of aircraft manufacturers are now equipping their products with this accessory as the modern engine used in commercial aircraft makes such a starter a necessity. It is well suited for aviation use as the average weight of the system is only 27 pounds, and its use eliminates hand-starting and cranking inasmuch as it is operated in the same manner as the starter used in the modern

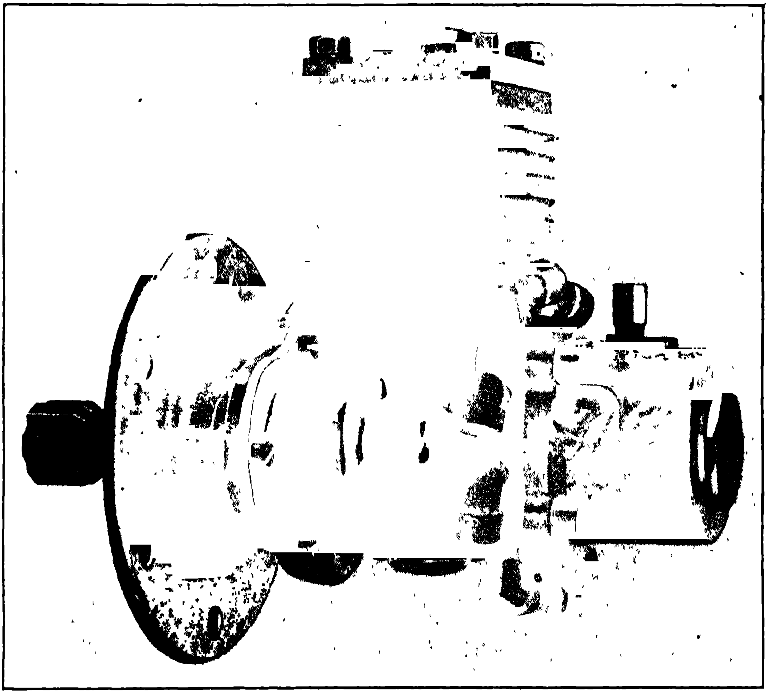


Fig. 820.—Air Compressor and Distributor of Heywood Air Starter has Standard Starter Flange Mounting for Attachment to Motor.

automobile of today. The pilot, seated in the cockpit of his plane, merely pulls the starting button; and due to the rapid operation of the starter's mechanism, the engine responds almost instantly. The Heywood starter has been under test with the government for the last three years and has been accepted to a point where several engine manufacturers are designing their engines for its adaption. One of the severest tests was on the engine of the successful plane which was used by Captain Wilkins in his Arctic Expedition, the starter functioning perfectly in extreme cold temperatures; also was used on the Stinson plane which won the National Air Tour of 1927.

A general description of the Heywood starter is as follows:

One size of Heywood High Pressure Injection starter is suitable for small automobile engines and up to 800 horsepower aviation engines. The starter tank which is governed at 400 pounds pressure of air is 26 inches in length and six inches in diameter and supplies the power to start rotation and the injection to run the engine. The compressor which is shown at Fig. 820 and which is driven by the aviation engine never requires over one-quarter horsepower and is capable of refilling the tank with air which

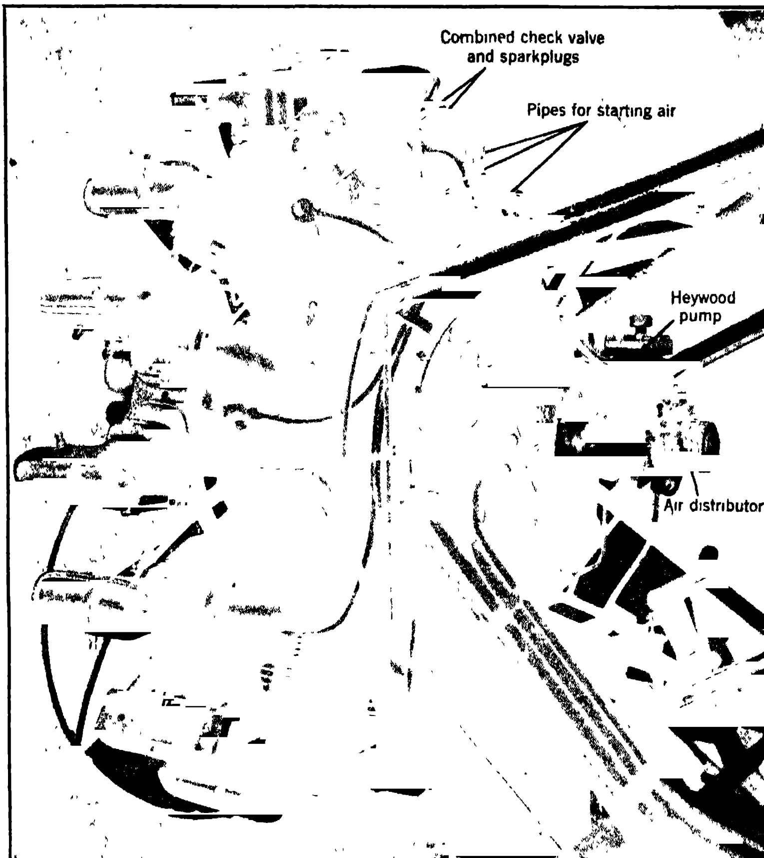


Fig. 821.—Showing Application of Heywood Air Starter to Wright "Whirlwind" Engine. Note Pipes Leading from Distributor to Combined Check Valve and Sparkplug Fittings on Cylinders.

is used for one start in about one minute. The weight of the complete starter averages 25 pounds to 30 pounds according to the adaption. The method of fitting the compressor to a Wright "Whirlwind" engine is shown at Fig. 821. When starting the engine, the pilot primes in the usual way; but the gasoline used in priming does not go to the cylinders or in the

manifold of the engine but goes into a carburetor or gas chamber on the starter where it is held until the starter button is pulled.

The operation of the starter is as follows:—The engine is primed in the usual way. The ignition is switched on, and the starter button is pulled. This pull allows the air to be released from the tank and goes through a tube to the starter into a chamber where it comes in contact with a rotating disc that has been timed with the engine. A hole in this disc allows the air to go through into a stationary disc to the proper tube leading to the cylinders which are on their power stroke thereby starting the engine in rotation. Simultaneously, part of this air in front of the rotating disc goes through a smaller hole back in on top of the gasoline that was put in the gas chamber by priming and starts forcing that gasoline through a small carburetor nozzle that projects through the center of the rotating disc up to a hole that opens to the stationary disc leading to the pipe that goes to the cylinders coming up under compression thereby giving these cylinders a richly carburetted mixture ready to fire; and the ignition being turned on, the engine starts running. During this action, the air keeps on forcing the pistons down on their power strokes, and the gasoline continues out of the gas chamber to the cylinders on compression until the gasoline has been exhausted from the starter gas chamber, which is sufficient to start any efficient engine under any weather conditions. The average engine is rotated by the Heywood starter from 400 to 500 r.p.m. In the end of the starter tank, there is a governor which controls the pressure when it reaches the adjusted point, usually 400 pounds. After starting, the automatic governor device allows the refilling of the tank with air until the pressure comes up to the adjusted point again.

It is believed by the makers that the upkeep is far lower than that of any other starter. From instructions furnished by the makers Service Department, the ordinary aircraft mechanic can make the complete installation. One advantageous factor of the Heywood starter is that no damage can come to the aviation engine from the starter's use which eliminates the damage that is customary from backfiring and also allows starting or use of the starter while on flight which would bring about a noticeable momentary acceleration of the engine. Also another factor is the reduced stress on the parts of the engine when starting by a cushion start effect. Also when using a multi-engined plane, the pilot can start either or all engines from the cabin or pilot's seat. The starter can also be used in testing new engines allowing the operator to have from ten to twenty starts with one tank of air before it is necessary to allow the engine to run to make a refill. Lubrication is taken care of from the oil line of the aviation engine and needs no care. The principal boon of the Heywood starter to the aviation enthusiast is that it spins the engine at a fast rate and needs only one man to make the start affording simple assembly and ease in operation.

Eclipse Hand and Electric Inertia Starter Series VII.—This starter shown at Fig. 822 A which operates on the principle of the storing of energy in a flywheel, was designed to fill the need for a light and efficient unit capable of cranking an airplane engine at high speed and satisfactorily starting the same during cold weather without the use of an auxiliary booster magneto, or like devices. The Series VII starter is recommended

for use with engines of 2,500 cubic inch displacement, or smaller. The advantages of this type starter are obvious. The operator is enabled to make a start either on the ground or in the air merely by pressing a push button. This feature will be found particularly valuable in the case of a forced landing or with an engine stalling in flight. Cold weather starting is greatly facilitated because an instantaneous speed of approximately 125 r.p.m. of the engine crankshaft is attained, and this speed insures delivery of gas to the cylinders and also permits of starting with a fully advanced spark. Attached to a standard Liberty engine, five to six complete revolutions of the propeller are obtained from one loading of energy in the flywheel. The amount of current consumed is entirely independent of the

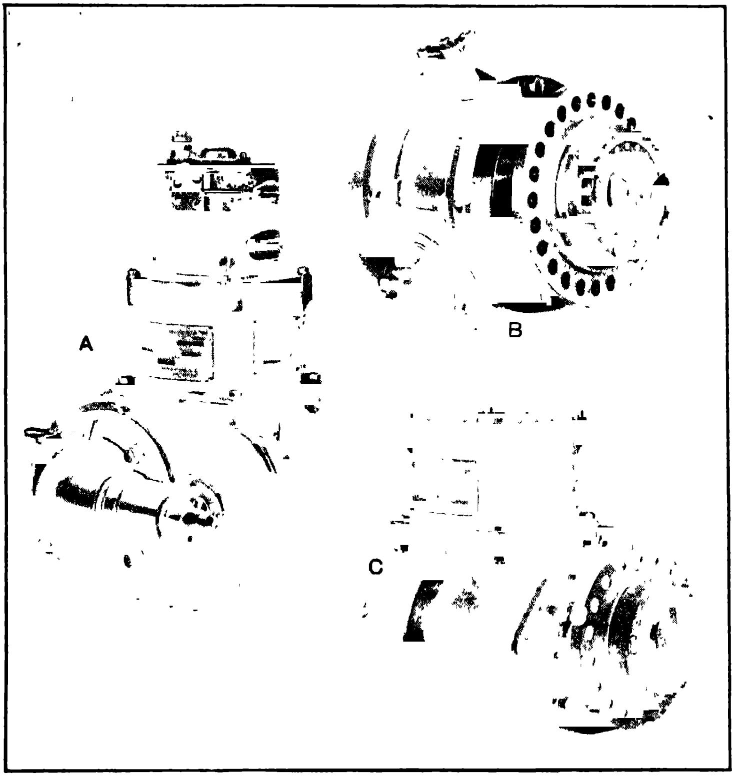


Fig. 822.—Eclipse Aviation Engine Starters. A—Combination Hand and Electric Inertia Starter. B—Concentric Type Inertia Starter. C—Hand Inertia Starter.

stiffness or temperature of the engine, as the electric motor is merely used to accelerate a flywheel to a maximum speed of approximately 16,000 r.p.m., whereas in the electric starting motor type, the crankshaft is turned directly by the motor armature through gearing.

The starter as furnished can be operated at will either manually or electrically. If, however, electrical equipment is not contemplated on the plane, the starter can be furnished without the electric motor, as shown at

Fig. 822 C a cover plate being mounted in its place. In such a case, however, the motor can be applied at a later time without any change other than the removal of the plate, and the applying of a motor, which is held in place by four screws. The weight of the combination unit is 35 pounds. Without the electrical attachment the weight is 27 pounds. Despite its remarkably light weight, the device is sufficiently rugged to operate satisfactorily indefinitely.

The flywheel is brought up to speed either manually or electrically, and the energy stored in same is released at the will of the operator by manually engaging it through a gear reduction drive, clutch and engaging

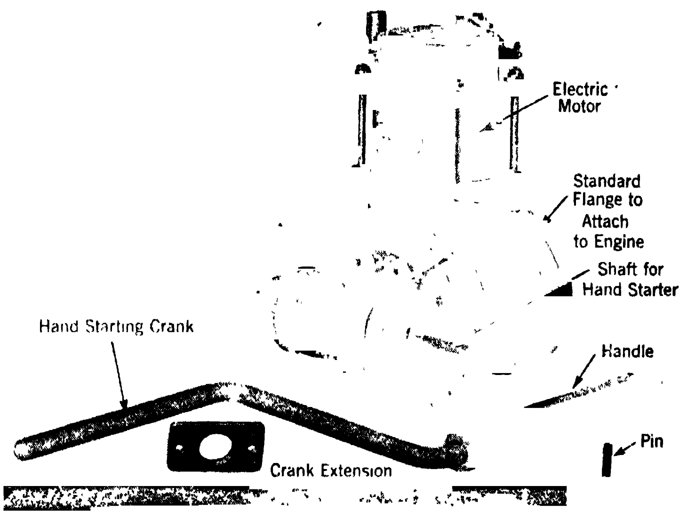


Fig. 823.—Eclipse Combination Hand and Electric Starter. Crankshaft Can be Turned by Energy Stored in Flywheel of Starter which May be Rotated Either by Hand Crank or Electric Motor.

mechanism with the crankshaft of the engine. The clutch is of the multiple disc type operating in grease, and can be adjusted for any predetermined torque to suit the engine to which the starter is applied. The purpose of this clutch is to provide a disconnection in the drive in case of engine backfire, thus effectively preventing damage to any part of the mechanism. The electric motor is arranged to automatically engage with the flywheel upon closure of the electric circuit, and to disengage when the circuit is broken, thus relieving the starter at all times of any losses due to brush friction, particularly when hand cranking. The normal speed of the flywheel is 16,000 r.p.m. when accelerated electrically. This speed can easily be reached manually, and even exceeded. In some instances, however, it is possible to effect a start with a flywheel speed as low as 9,000 r.p.m. From this an idea can be formed of the amount of reserve power present when the flywheel is fully accelerated. The minimum speed to effect a start can be procured electrically in from two to four seconds time

with a normal battery. From twelve to fourteen seconds is required to attain maximum flywheel speed. When accelerating by hand, maximum speed can be obtained in about one minute, depending upon the operator.

The electric motor is designed to operate in conjunction with a twelve volt airplane type storage battery. The average current consumption is 120 amperes. Assuming that a fifteen ampere, fifteen volt generator is used at normal cruising speeds, an empty battery should be completely replenished in from five to six minutes time. Application of the unit can be made to practically any existing type of engine. Eighteen holes, twenty degrees apart are located in the mounting flange of the starter to permit of mounting the same at almost any desired angle, thereby greatly assisting in its easy application. If desired, the starter can be mounted in a completely inverted position without affecting its operation in any way. Provision has been made for cranking by hand from either side of the plane as desired, and in addition the hand crankshaft can be varied through a fifteen degree angle, either upwards or downwards with respect to the center line of the starter. This feature, combined with the ability to rotate the starter at the mounting flange, makes possible the location of the hand crank in the most accessible position when applying the starter to the ship. A manual hand crank with fixtures is furnished with each starter. Moving parts are completely enclosed and protected against ingress of dust. No lubrication of any kind is required, as the starters when shipped from the factory contain sufficient lubrication to last indefinitely. The inertia starter is also made in the concentric form as shown at Fig. 822 B, well adapted to radial engines. This type is described in detail as it is a very popular type. A modified form permits of cranking from the cockpit, making a one man start possible.

Eclipse Electric Starter, Twelve Volt.—This starting motor shown at Fig. 823 has been designed to mount at the ignition end of the Liberty twelve-cylinder engine, and is also applicable to such engines as the Curtiss, Wright and Packard, etc. The application of this type of starter has been considered standard by aviation engine manufacturers, and almost all of them are building their engines to receive this starting motor. This motor is furnished as a combination electric and hand unit. If desired as an electric starter only, it can be furnished without the hand attachment. Practically all of the installations of this starter are in the form of the combined electric and hand unit. The starting motor operates in conjunction with a suitable twelve volt battery, of a size depending upon capacity, as well as other uses to which the battery may be put. Batteries are obtainable in weights ranging from 35 pounds to 70 pounds. Detailed information on batteries may be obtained direct from the battery makers. The unit will crank a standard twelve-cylinder Liberty engine at a speed of approximately 30 r.p.m. It consists of a small electric motor geared at a ratio of 100 to 1, the power of which is transmitted to an automatic engagement mechanism merely by closing an electrical switch contact. Disengagement is also effected automatically when the engine fires. A backfire release mechanism in the form of a multiple disc clutch is incorporated in the starter to prevent damage to the driving mechanism in the event of a backfire. It is designed, in the form shown for engines of 2,000 cubic inches displacement or smaller.

A hand crank attachment has been incorporated in the design of this device, such that should a storage battery not be available, the device may be used as a suitable hand crank, giving a reduction of approximately twenty to one, and using the same automatic meshing and demeshing mechanism, as well as backfire damage prevention device, as when the device operates as an electric starter. Means have also been provided for preventing backward rotation of the hand crank in case of backfire, thus preventing any possibility of injury to the operator. This hand crank attachment has been designed so that the engine can be cranked from either side, and by turning the crank handle in either direction, merely by the interchange of parts when assembling the hand crank unit. For outboard engine installation, that is for multiengine airplanes or airships, a magnetically-operated, remote control solenoid switch and pilot push button switch are provided. This saves starting cable weight and makes for complete control of the electrical starting equipment within reach of the pilot. In addition to this, multiengine ships may be operated from a single battery. The total weight of the complete unit is 34 pounds. The above unit is suitable for engines up to 450 horsepower. Provision has been made for applying a larger electric motor with additional weight of 4½ pounds for engines in excess of 450 horsepower.

The Bristol Gas Starter.—The large Beardmore engine previously shown and other large engines are said to be easily started by the Bristol gas starter, despite large size. The starter consists of a small air-cooled, single-cylinder, two-cycle engine driving a pumping cylinder that draws a supply of gasoline vapor and air from the carburetor of the starter engine and delivers it under pressure to the cylinders of the main engine. The delivery of the mixture to the latter is controlled by a small disc-valve distributor driven from the main engine at half the crankshaft speed and arranged so that the mixture enters the cylinders, first on the firing stroke and secondly for a part of the induction stroke. To avoid the loss of pressure which would occur from the escape of gas through the open inlet valves on the induction stroke, the port in the distributor is first closed this period by a spring-loaded mushroom valve, but when the main engine begins to turn freely, a hand lever is raised to open the valve referred to, gas then being admitted on the induction stroke. After a complete revolution in this condition, the cylinders and the whole of the induction system are thus filled with gas. Although the starter engine has only one cylinder, it is fitted with a two-cylinder type magneto and the second ignition lead is connected to the distributor of the magneto of the main engine. For the first part of the starting operation, this second lead is short-circuited, but when the main engine is turning freely and has been filled with gas as described, the short-circuiting switch is opened and the engine then fires and picks up on its own carburetors. A nonreturn valve is fitted in the starter connection to each cylinder of the main engine to isolate the starter when the engine is running normally.

The starter will maintain a gas pressure of 140 pounds per square inch, and it is capable of starting high-speed gasoline engines with cylinder capacities up to 2,500 cubic inches or slow-speed oil engines up to 5,000 cubic inches capacity. An important feature of the arrangement is the fact

that the only connections between the main engine and the starter are a small-bore pipe and a high-tension lead, and it is thus possible to locate the starter in any convenient position up to twenty feet from the engine. The weight of the starter unit is 50 pounds, so that it is suitable for use with aircraft engines, and, as the starter engine can be run continuously without overheating, it can be used for driving auxiliaries such as wireless generators at such times that the plane is not in flight, a very convenient thing if a large seaplane was forced to alight away from shore or a commercial airplane had to land in a remote locality. The small generators ordinarily used for radio current are usually driven by small air propellers that will turn only when the airplane is in flight, so a power driven unit will make the radio operative even when the airplane is not in flight due to failure of the main powerplant.

Eclipse Series "6" Starter.—The eclipse aviation engine starter series "6," is furnished in the following models:

With Type "A" Hand Crank		*Dimension*	*With Type "B" Hand Crank*	
Model	*Rotation*	*Flange to Jaw*	*Model*	*Rotation*
M-1900	clock	1-7/16"	M-1938	clock
M 1904	anti-clock	1-9/16"	M-1932	anti-clock
M-1918	clock	1-9/16"	M-1939	clock

The Series "6" Starter is of the concentric inertia type. Although particularly adaptable to engines of the radial type, it is equally suitable for starting those of the Vee type, as well as those with cylinders in line and will perform efficiently on engines up to and including 1,300 cubic inch displacement. Operation depends upon the storage of energy in a flywheel which is brought up to a high speed by manual operation of the hand crank. The high speed is attained through multiple gearing. The stored energy is then disbursed at the will of the operator in cranking the engine. Included in the mechanism is a torque-overload release, which prevents abnormal stresses in the mechanism, should the engine back-kick while cranking. A sectional view of the device is shown at Fig 824.

The drive from the flywheel to the engine passes through the following stages:—From the flywheel, through spur-gearing, to a counter-shaft, which is in turn spur-geared to an internal gear having an integral sun pinion, to a final planetary drive. The planetary gears are mounted in a cage built into the end of a barrel assembly and mesh with a stationary internal gear. The barrel assembly rotates at engine crankshaft speed. The drive then passes through the torque-overload release, which is in the form of a multiple disc clutch under adjustable spring pressure, to an internally threaded nut member within which is threaded a longitudinally slidable screw shaft splined to the starter driving jaw at its outer end. The meshing jaw is advanced through the medium of a compression spring and may be withdrawn by direct pull from the operating rod if for any reason the engine does not start and comes to rest with the jaws in mesh. All bearings are of the ball type and are standard except for those mounting the driving barrel. These are of the built-up cone type, and adjustment is provided for assembly purposes. Fifty-eight best quality steel balls are used at each end.

To apply this starter to the engine, remove the crankcase plate covering the opening to be occupied by the starter. Examine the end of the crank-shaft, ascertain if the engine jaw is the proper one, and make sure that it mates with the corresponding jaw on the starter. Before proceeding further, be definitely certain that the outermost point of the engine jaw is $1^{11}/_{16}$ inch from the crankcase flange. However, in applying to Wright engines of the "J" series, the distance from the crankcase flange to the outermost point of the engine jaw is $1^{9}/_{16}$ inch. The difference is taken up in the starter jaw, which is the only part affected. In any case there

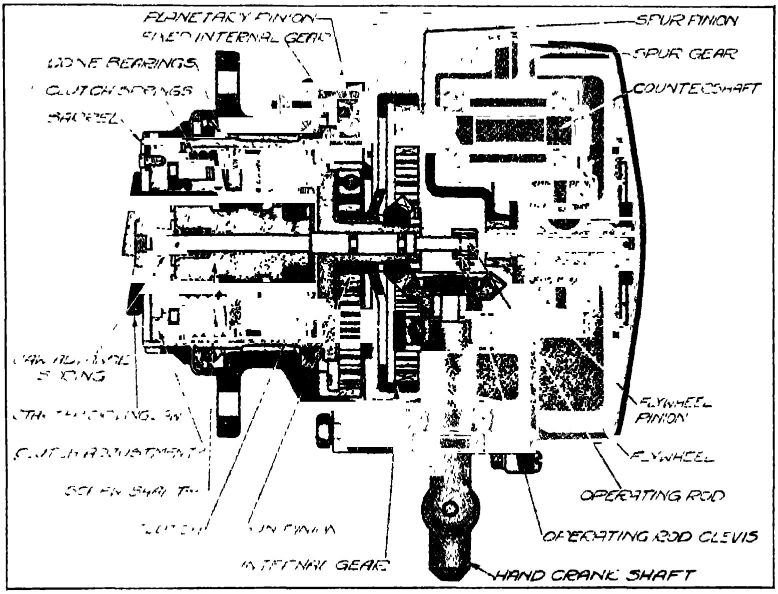


Fig. 824.—Sectional View of Eclipse Series 6 Concentric Starter Showing Internal Mechanism.

should be approximately ⅛ inch clearance between the engine jaw and starter jaw when the latter is out of mesh. This should always be checked when making an application. (See application dimensional drawing Fig. 825.)

The engine jaw is usually splined and mates with corresponding splines on the end of the crankshaft extension, or, in engines using an impeller, mates with splines on a counter shaft geared to the crankshaft. In most cases it is held in place longitudinally by means of a long screw extending through to the crankshaft to which it is threaded and locked by a heavy positive lockwasher. The studs used for bolting the starter to the engine are furnished with the engine Standard nuts and lock-washers are used. Starters applied to engines to mesh directly with the crankshaft and to crank engine in a clockwise rotation (looking at the rear of engine) should be so mounted as to bring the hand crankshaft through the right side of the fuselage. The hand crank is then turned in a clockwise direction, the operator facing the propeller. For engines equipped with blowers and in

which the starter applies to a geared shaft to crank counter-clockwise (looking at the rear of the engine) the starter is mounted on the engine so as to bring the hand crankshaft through the left side of the fuselage. The hand crank is then turned in a counter-clockwise direction, the operator facing the propeller.

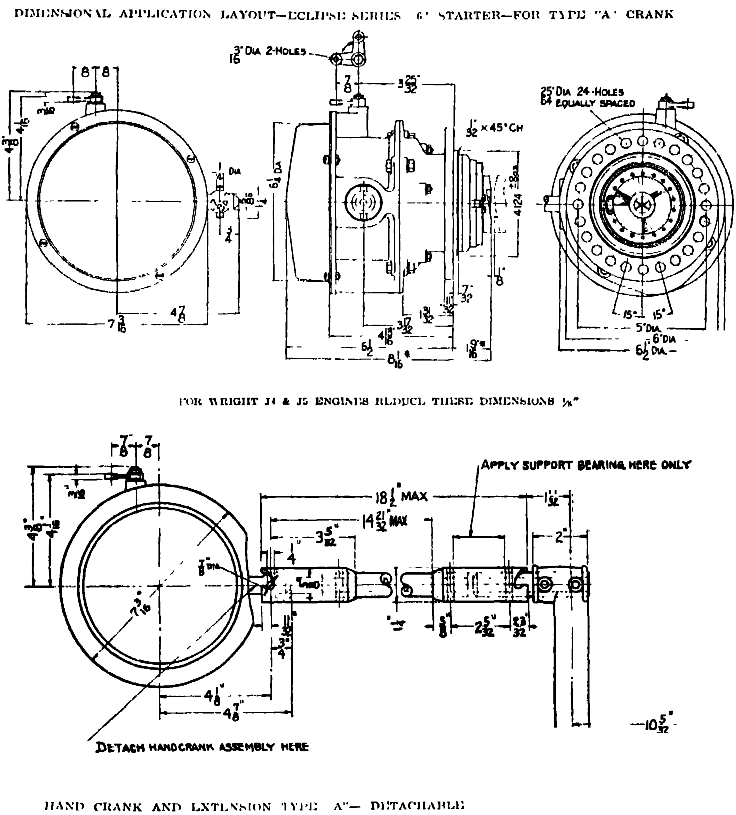


Fig. 825.—Eclipse Series 6 Starter for Type A Crank.

The cranking shaft extending from the starter carries a ball and pin drive and provides for any slight mis-alignment of the hand crank assembly. Full details of hand crank construction are shown in Figs. 825 and 826. The hand crank assembly consists of a crank handle proper together with an extension tubing assembly. This extension assembly may be advantageously applied in either of the following positions:

The extension assembly may be permanently pinned to the crank handle, thus permitting the entire crank assembly to be applied to the starter shaft and removed at will as shown at Fig. 825.

The extension assembly may be permanently pinned to the starter shaft,

thus leaving the crank handle only to be attached or detached as desired. This assembly is shown in Fig. 826.

In either case, a spiral slot is used to automatically disengage the hand crank when the operator ceases cranking. For either method of application the outer end of the extension tubing assembly is supported by a support bearing, (not furnished) mounted on the side of the fuselage.

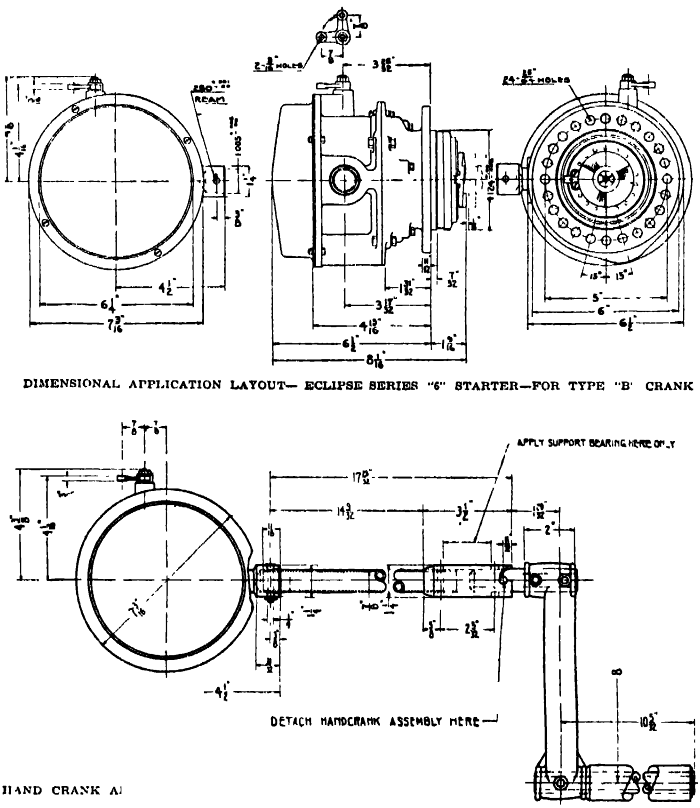


Fig. 826.—Eclipse Series 6 Starter for Type B Crank.

In order to obtain maximum strength and reliability for a given weight the extension assembly is made of three individual parts consisting of two substantial heat-treated steel ends, with a piece of tubing between. If the extension tubing is too long for any particular application, one jaw may be removed and the tubing severed to the required length, and the jaw re-attached. **Important**:—The supporting bearing should be applied to the steel end, into which the crank handle assembles, the bearing being located between the two pins. In no case should the support be taken on the intermediate tubing, as such an installation places undue bending

stresses on this latter part and bending will occur. However, the crank-handle assembly is so strong and durable that no bending or other difficulty will be experienced if these instructions are followed. All pins used and furnished with the crank handle assembly are of heat-treated chrome nickel steel and no pins or bolts other than those furnished should be substituted. The same extension assembly may be used for starters of either direction of rotation. The spiral slots in the steel ends are of opposite direction, and inasmuch as only one spiral slot is used, choice of direction of rotation may be had.

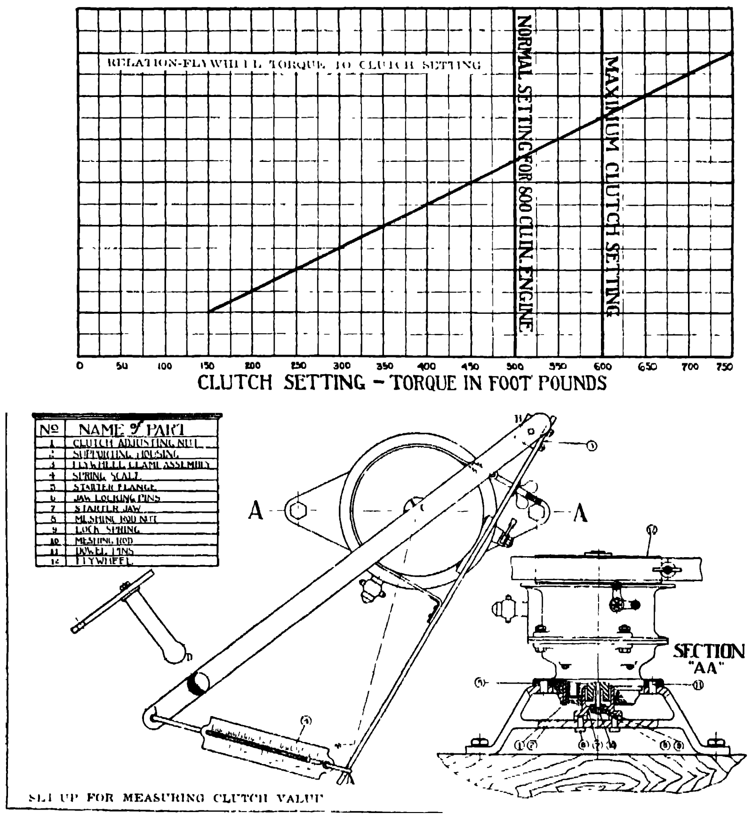


Fig. 827.—Chart at Top Shows Relation of Flywheel Torque to Clutch Setting. Lower Illustration Shows Set-Up for Measuring Clutch Value.

The cranking shaft extending from the starter, with which this type of hand crank is used, has in its end an internal tapered bore to receive the hand crank assembly as shown in Fig. 826. The hand crank assembly consists of two units, a crank handle proper and the extension assembly. The extension assembly is particularly designed to be permanently pinned to the starter shaft, leaving the crank handle only to be attached or detached as desired. The extension assembly is made from thin wall heat-

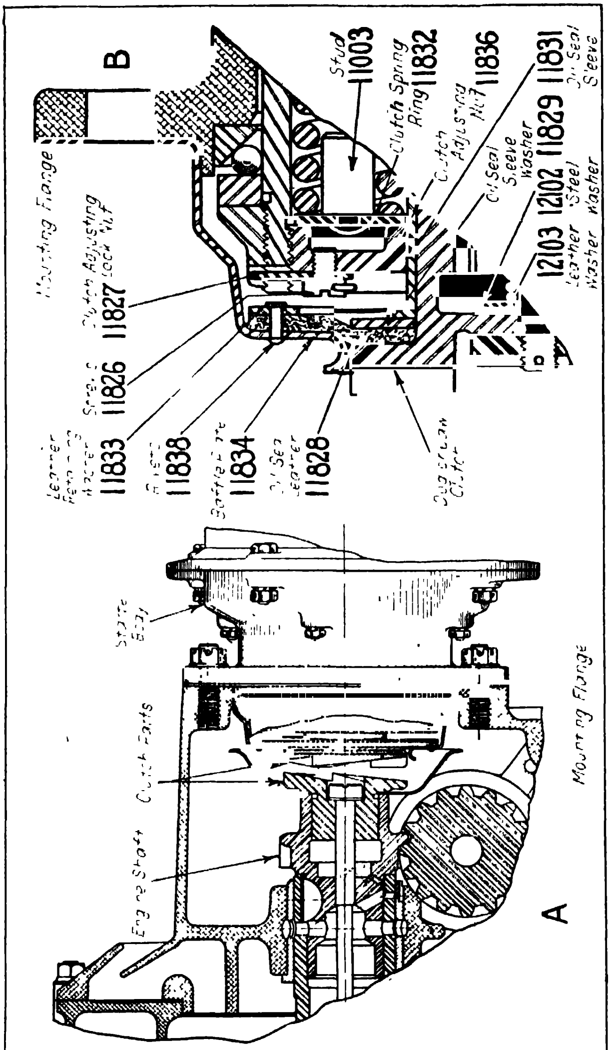


Fig. 828.—Oil Shield Installation for Eclipse Starter Shown at A and Parts of Oil Seal Outlined at B.

treated steel tubing, the end being re-inforced with a steel plug. The end of the tubing is tapered such that after being pinned to the starter shaft there is sufficient universal action to provide for any slight mis-alignment of the hand crank assembly. The one end of the extension assembly is pinned to the starter shaft with a ¼ inch diameter pin which is a snug fit in the starter shaft but a clearance fit through the extension assembly, thus permitting universal action between the two. This pin is held in place by means of a cotter pin. The opposite end of the tubing is pinned to a hardened steel end piece which engages with the hand crank through a spiral slot. By the use of this spiral slot the hand crank is automatically

disengaged when the operator ceases cranking. **Important:**—The support bearing should be applied to the steel end into which the crank handle assembles, and not to the smaller diameter tubing. Care should be taken when mounting this bearing to line it up as closely in line with the starter shaft as is possible. This type of hand crank assembly is obtainable for starters of either direction of rotation.

The starter is meshed by means of an operating rod extending from the starter, at the protruding end of which is keyed a lever with two arms at right angles. This provides for connecting an operating linkage running either to the side of the fuselage, or to the cockpit, or both, as is desired. This lever may be adjusted to any ninety degree position required. Although it has been found that a flexible wire may be used, the makers recommendation is that a stiff rod be provided to manually operate the starter engagement, inasmuch as, should the engine fail to start, it may be necessary to withdraw the starter jaw from engagement with the engine jaw, the accomplishment of which necessitates pushing the rod inward. In most cases the starter jaw will withdraw automatically, but if it should not the above operation may be resorted to. When the engine fires, the disengagement is automatic.

Operation of Eclipse Series "6" Starter.—To start the engine, put the hand crank in place. Inspect the operating rod and make certain that the rod is in the disengaged position, assuring that the jaws are demeshed. Revolve the crank handle in proper direction of rotation. Best results are obtained by starting the cranking operation rather slowly without exerting any great force until an appreciable speed is attained, then exerting greater pressure on the crank handle as the speed increases. Efficient starting results are obtained at a maximum crank handle speed of 75 to 80 r.p.m. When maximum speed is reached remove the crank handle and with the spark advance lever fully advanced, turn on the ignition switch and pull the operating rod. It will be found that the use of a booster magneto is in most cases not necessary but if used will naturally facilitate starting, particularly in cold weather. When the engine starts, no further attention to the starter is necessary, the disengagement being automatic. If, however, the engine fails to start, push on the operating rod to insure disengagement of the drive and repeat the operations outlined above.

Maintenance.—This starter should operate for thousands of starts without any attention whatsoever. **Do Not Lubricate.** All starters are properly and sufficiently lubricated at the factory. The addition of further lubricant will undoubtedly be injurious, as successful operation depends upon the free rotation of parts and improper lubrication will be detrimental. Should any trouble be experienced with the mechanism the makers emphasize that it is their preference that the starter be removed from the engine and returned to the factory for necessary attention and prompt service will be rendered. If, perchance, the starter may have been disassembled, it is highly important that it be entirely cleaned before reassembling. After cleaning, oil the flywheel bearings with a *slight* amount of a good grade of light oil, also placing a slight amount of light beafing grease between the two ball bearing assemblies, but *not* actually on the bearings themselves. All other parts should be covered with No. 32 *Gredag.* It is extremely *important that no other lubricant than that specified be used.*

CAUTION:—If for any reason the starter should be taken apart, be extremely careful that the following precautions are observed:

1. See that operating lever may be freely manipulated. The travel of the starter jaw should be ⅜ inch.
2. See that starter can be turned over by applying rotation, by hand only, to exposed end of the driving barrel.
3. See that starter jaw has $\frac{5}{16}$ inch endwise travel under spring pressure when holding operating rod in out-of-mesh position.
4. See that the driving barrel has no appreciable side or end play.
5. The clutch must be accurately reset to 500 foot pounds. Too low a value will prevent cranking of the engine while too high a value may cause serious injury to either the engine or starter mechanism.

Clutch Setting.—All Series "6" starter clutches are carefully set at 500 foot pounds at the factory, prior to shipment. No alteration in clutch setting should be necessary throughout the life of the starter. If, however, it is desired to reduce the setting to protect an engine drive, or increase the setting to operate an engine requiring a greater torque than that for which the clutch has been set, remove the clutch adjustment nut lock and insert a spanner wrench in the holes provided therefor in the adjustment nut. Turning the nut in an anti-clockwise rotation reduces the setting, while turning it in the clockwise direction increases the setting. Inasmuch as the clutch adjustment lock also locks the barrel adjustment of the bearings on which the barrel assembly is mounted, great care should be taken not to disturb this adjustment when resetting the clutch. The safest method is to examine the bearing adjustment carefully after making a clutch adjustment and reset if necessary.

When starters are shipped from the factory, a dust protection, in the form of a cover, is mounted on the forward end over the starter jaw. This is for protection during shipment to exclude foreign matter from entering the starter bearings. This cover should not be removed until mounting the starter to engine and should then be returned to the factory at Hoboken, New Jersey, U. S. A.

Determination of Clutch Value.—If the position of the clutch adjustment nut has been disturbed or the clutch reset, or if for any other reason it is deemed necessary to measure the torque value, the procedure as outlined below should be followed. The method used and the apparatus necessary are shown in Fig. 827.

The apparatus consists of the following parts:

Supporting Housing	Part No. 4306
Flywheel Clamp and Lever Arm	Part No. 4307
Spring Scale	Part No. 4311

The supporting housing is designed to be mounted to the starter flange and doweled to two opposite holes in the flange. On the inside of the housing, in proper position to register with the teeth in the starter jaw are three pins rigidly mounted in the casting, for the purpose of locking the driving end of the starter against rotation. The housing is so shaped that it may act as a stand to support the starter on the work bench. For the purpose

of measuring torque at the flywheel a flywheel clamp arm "AB" is provided, having an auxiliary lever arm "BE" pivoted to the clamp arm at one end, with means for mounting the spring scale between the opposite projection "A" of the flywheel clamp arm and the lever "BE." With such an arrangement handle "D" may be pulled, maintaining the angle "EAC" 90 degrees.

To measure the torque of the clutch proceed as follows:—Remove the cotter pin and meshing rod nut from the end of the meshing rod of the starter, and then remove the lock ring and starter jaw. By inserting a knife blade between the housing and the baffle plate, the latter may then be removed. After removing the baffle plate, the starter jaw and the meshing rod nut may then be re-assembled and the starter mounted to the supporting housing, jaw end down, so that the starter pilot registers with the bore in the supporting housing, also registering the dowels in the latter with two opposite holes in the starter flange. Rotate the flywheel, if necessary, to register the pins in the housing with the three teeth on the starter jaw.

Remove the flywheel cover and place the flywheel clamp arm around the flywheel, locking it tightly thereto. Care must be taken to prevent accumulation of any dust or dirt at the flywheel end of the starter, as the flywheel is rotated on high speed ball bearings and the entrance of dirt at this point is highly detrimental.

Hook the end of the scale in the hole in the end "A" of the clamp arm, and the opposite end in the hole "E" in the arm "BE"; then pull on the handle. When taking a reading, the flywheel should be rotated at as high a speed as is possible consistent with maintaining a constant speed. In as much as the distance from the center line of action of the scale to the flywheel center is one foot, the scale reading, after correcting for any initial reading, represents torque in foot pounds at the flywheel.

After having taken a reading as described in the latter paragraph and correcting for initial reading, determine the clutch setting by referring to the curve at the top of Fig. 827. This curve shows the relation of flywheel torque in foot pounds plotted as the vertical ordinate, to the clutch setting in foot pounds torque plotted as the horizontal ordinate. For instance, at a normal clutch setting of 500 foot pounds, the spring scale should register 4.5 foot pounds torque at the flywheel. The curve has been marked for a maximum clutch setting of 600 foot pounds, which value should not be exceeded in order not to overstress the starter in the event of back-kick. The curve also indicates a normal clutch setting for engines of 800 cubic inches as 500 foot pounds, which has been found to be the most practical setting. In general clutch settings are dependent upon the size of the engine, the torque capacity of the starter and the torque transmitting parts. Too low a setting will cause clutch slippage in cold weather, while if the maximum setting is exceeded damage to the mechanism is liable to result.

The engine jaw application in the case of the Wright "Whirlwind" engine is illustrated in Figure 828 A. In order to prevent oil splashed from the engine gears from entering at the central portion of the starter, an oil thrower (part No. 11,835) is mounted on a shoulder on the engine jaw (part No. 11,526) and clamped between the crankshaft extension and the engine jaw by means of a bolt (part No. 11,765) and a lockwasher.

Care must be taken to see that the oil thrower is mounted on the shoulder of the engine jaw so that it does not fall into the undercut at the end of the splines. This can best be checked by screwing the bolt all the way home and then backing it off approximately one revolution. The thrower may then be gripped at the flats with the thumb and the middle finger and rotated to check for concentricity with respect to the crankcase, at the same time ensuring that no side-play is present. In this manner it may easily be determined whether or not the oil thrower is properly located. The bolt may then be retightened.

An oil seal has been incorporated on all Series "6" starters as illustrated in Figure 828 B. This is to prevent seepage of oil from the engine crankcase into the starter housings. A baffle plate is provided to completely cover the portion of the starter protruding into the crankcase, to protect the starter from oil splash. A leather seal is also assembled within the baffle plate, back of the starter jaw, in the event that the oil level, for any reason, approaches the opening in the baffle plate.

QUESTIONS FOR REVIEW

1. Name important classifications of airplane instruments
2. Why are engine instruments important?
3. Name necessary instruments all airplanes should be equipped with and state their purpose.
4. What methods have been proposed for airplane propulsion?
5. What is the difference between an "adjustable" and a "variable" pitch propeller?
6. Describe construction of standard metal propeller.
7. How is Curtiss-Reed metal propeller made?
8. Describe Heywood air starting system.
9. What forms of electric starters are available?
10. What is the value of propeller speed reduction gearing?
11. Describe Eclipse Series 6 Starter.
12. Why is proper starter clutch spring pressure important?

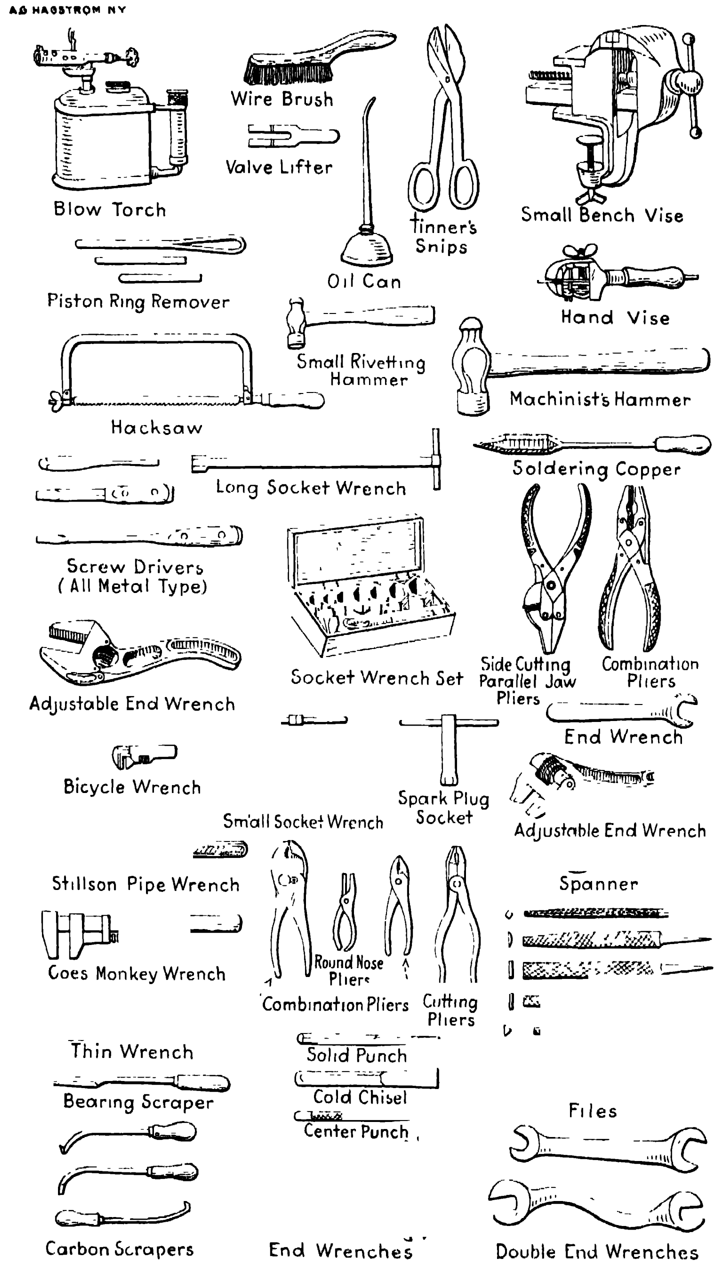


Fig. 829.—Practical Hand Tools Useful in Dismantling, Repairing and Re-assembling Airplane Engine Parts.

CHAPTER XLIII

SMALL TOOLS USED IN MOTOR REPAIRING

Tools for Adjusting and Erecting—Forms of Pliers—Miscellaneous Tools—Hammers and Mallets—Special Forms of Wrenches—Use and Care of Files—Split Pin Removal and Inserting Tools—Complete Chisel Set—Hand Drilling Machines—Drills, Reamers, Taps and Dies—Types and Use of Reamers—Use of Taps and Dies—Measuring Tools, Calipers—Rules and Scales—Vernier and Its Use—Micrometer Calipers and Their Use—Hints for the Care of Tools—Typical Tool Outfits, Curtiss OX—Hall-Scott Tools—Napier-Lion Engine Kit—Hispano-Suiza Tool Kit—Stands for Overhauling Airplane Engines.

Tools for Adjusting and Erecting.—A very complete outfit of small tools, some of which are furnished as part of the tool equipment of various engines are shown in group at Fig. 829. This group includes all of the tools necessary to complete a very practical kit and it is not unusual for the mechanic who is continually dismantling and erecting engines to possess even a larger assortment than indicated. The small bench vise provided is a useful auxiliary that can be clamped to any convenient bench or table or even fuselage longeron in an emergency and should have jaws at least three inches wide and capable of opening four or five inches. It is especially useful in that it will save trips to the bench vises, as it has adequate capacity to handle practically any of the small parts that need to be worked on when making repairs. A blow torch, tinner's snips and soldering copper are very useful in sheet metal work and in making any repairs requiring the use of solder. The torch can be used in any operation requiring a source of heat. The large box wrench shown under the vise is used for removing large special nuts and sometimes has one end of the proper size to fit oil drain chamber caps. The piston ring removers are easily made from thin strips of sheet metal or hacksaw blades with the teeth ground off and surfaces ground down, securely brazed or soldered to a light wire handle. These are used in sets of three for removing and applying piston rings in a manner to be indicated. The uses of the wrenches, screwdrivers, and pliers shown are known to all and the variety outlined should be sufficient for all ordinary work of restoration. The wrench equipment is very complete, including a set of open end S-wrenches to fit all standard bolts, a spanner wrench, socket or box wrenches for bolts that are inaccessible with the ordinary type, adjustable end wrenches, a thin monkey wrench of medium size, a bicycle wrench for handling small nuts and bolts, a Stillson wrench for pipe and a large adjustable monkey wrench for the stubborn fastenings of large size.

Forms of Pliers.—Four different types of pliers are shown, one being a parallel jaw type with size cutting attachment, while the other illustrated near it is a combination parallel jaw type adapted for use on round work as well as in handling flat stock. The most popular form of pliers is the combination pattern shown beneath the socket wrench set. This is made of substantial drop forgings having a hinged joint that can be set so that

a very wide opening at the jaws is possible. These can be used on round work and for wire cutting as well as for handling flat work. Round nose pliers are very useful also. The influence of aeronautics on the design of small hand tools is indicated in a set of three special pliers now offered by the Forged Steel Products Company, Newport, Penn., under the name of the "Aviator Kit." Recognizing that light weight is an essential factor in any item of airplane equipment, these pliers have been designed with special reference to that requirement, but their lightness entails no sacrifice of strength. They are hammer forged from electric furnace alloy tool steel, individually hardened in liquid heat process and electrically tempered through and through, in distinction to surface-hardening. Foremost in the group is a general use plier of exclusive design with a long thin nose brought to a decided point. Its chief features are hand-filed cutters that cut with ease, deeply milled gripping teeth and end grip, adjustable joint for expanding the gripping jaws and "vacuum grip" non-slip handles. The length of this plier is seven inches. For working in confined spaces inaccessible to ordinary pliers, the mechanic will find the 6½ inch long needle nose pattern a helpful adjunct. This pattern is also fitted with cutters and is deeply milled at the extremity of the jaws for securing a tight hold. The handles and jaws are spring tempered. The diagonal cutting nippers, shown in the illustration, measure six inches in length. They are light in weight, but are built for heavy duty work. This special Aviator's Kit shown at Fig. 830 weighs only eighteen ounces.

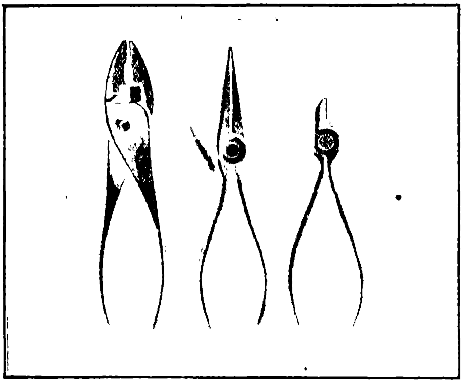


Fig. 830.—Special Aviator's Kit of Pliers.

Miscellaneous Tools.—A very complete set of files, including square, half round, mill, flat bastard, three-cornered and rat tail are also necessary. A hacksaw frame and a number of saws, some with fine teeth for tubing and others with coarser teeth for bar or solid stock will be found almost indispensable. A complete punch and chisel set should be provided, samples of which are shown in the group while the complete outfit is outlined in another illustration. A number of different forms and sizes of chisels are necessary, as one type is not suitable for all classes of work. The adjustable end wrenches can be used in many places where a monkey wrench cannot be fitted and where it will be difficult to use a wrench having a fixed opening. The Stillson pipe wrench is useful in turning studs, round rods, and pipes that cannot be turned by any other means though the careful mechanic makes as little use of this tool on finished parts as he can and then only to remove stubborn pieces that resist removal by other tools. Most piping used around aviation engines is thin walled copper or aluminum tubing so the Stillson wrench is not as necessary as it would be in a plumber's kit or for shop maintenance work. A complete shop kit must

necessarily include various sizes for Stillson and monkey wrenches, as no one size can be expected to handle the wide range of work the general repairman must cope with. Three sizes of each form of wrench can be used, one, a six inch, is as small as is needed while a twelve inch tool will handle almost any piece of pipe or nut used in construction of even large engines.

Hammers and Mallets.—Three or four sizes of hammers should be provided, according to individual requirement, these being small riveting, medium and heavyweight machinist's hammers. A very practical tool of this nature for the repair shop can be used as a hammer, screwdriver or

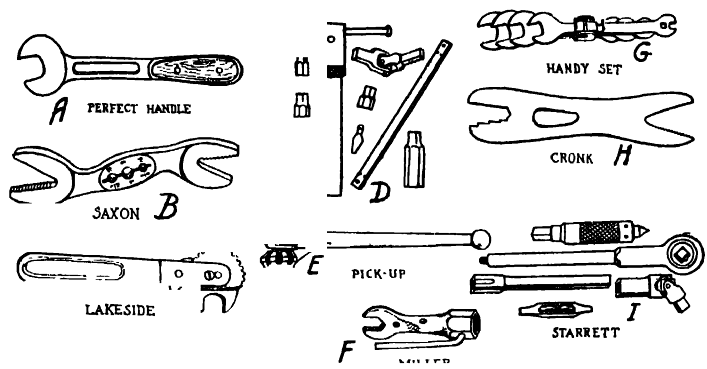


Fig. 831.—Wrenches are Offered in Many Forms.

pry iron. It is known as the "Spartan" hammer and is a tool steel drop forging in one piece having the working surfaces properly hardened and tempered while the metal is distributed so as to give a good balance to the head and a comfortable grip to the handle. The hammer head provides a positive and comfortable T-handle when the tool is used as a screwdriver or "tommy" bar. Machinist's hammers are provided with three types of heads, these being of various weights. The form most commonly used is termed the "ball pein" on account of the shape of the portion used for riveting. The straight pein is just the same as the cross pein, except that in the latter the straight portion is at right angles to the hammer handle while in the former it is parallel to that member. Another useful adjunct is a soft head hammer in which lead or rawhide is used which is very handy for driving against finished surfaces. Copper hammers are apt to be too hard. A wood head mallet and a rubber head mallet or large hammer should be included in the tool equipment.

Special Forms of Wrenches.—Wrenches have been made in infinite variety and there are a score or more patterns of different types of adjustable socket and off-set wrenches. The various wrench types that differ from the more conventional monkey wrenches or those of the Stillson pattern are shown at Fig. 831. The "perfect handle" is a drop forged open end form provided with a wooden handle similar to that used on a monkey wrench in order to provide a better grip for the hand. The "Saxon" wrench is a double alligator form, so called because the jaws are in the form of a V-groove having

one side of the V plain, while the other is serrated in order to secure a tight grip on round objects. In the form shown, two jaws of varying sizes are provided, one for large work, the other to handle the smaller rods. One of the novel features in connection with this wrench is the provision of a triple die block in the center of the handle which is provided with three most commonly used of the standard threads including 5/16-inch-eighteen, 3/8-inch-sixteen, and 1/2-inch-thirteen. This is useful in cleaning up burred threads on bolts before they are replaced, as burring is unavoidable if it has been necessary to drive them out with a hammer. The "Lakeside" wrench has an adjustable pawl engaging with one of a series of notches by which the opening may be held in any desired position.

Ever since the socket wrench was invented it has been a popular form because it can be used in many places where the ordinary open end or monkey wrench cannot be applied owing to lack of room for the head of the wrench. A typical set which has been made to fit in a very small space is shown at D. It consists of a handle, which is nickel-plated and highly polished, a long extension bar, a universal joint and a number of case hardened cold drawn steel sockets to fit all commonly used standard nuts and bolt heads. Two screwdriver bits, one small and the other large to fit the handle, and a long socket to fit sparkplugs are also included in this outfit. The universal joint permits one to remove nuts in a position that would be inaccessible to any other form of wrench, as it enables the socket to be turned even if the handle is at one side of an intervening obstruction.

The "Pick-up" wrench, shown at E, is used for sparkplugs and the upper end of the socket is provided with a series of grooves into which a suitable blade carried by the handle can be dropped. The handle is pivoted to the top of the socket in such a way that the blades may be picked up out of the grooves by lifting on the end of the handle and dropped in again when the handle is swung around to the proper point to get another hold on the socket. The "Miller" wrench shown at F, is a combination socket and open end type, made especially for use with sparkplugs. Both the open end and the socket are convenient. The "Handy" set shown at G, consists of a number of thin stamped wrenches of steel held together in a group by a simple clamp fitting, which enables either end of any one of the four double wrenches to be brought into play according to the size of the nut to be turned. The "Cronk" wrench shown at H, is a simple stamping having an alligator opening at one end and a stepped opening capable of handling four different sizes of standard nuts or bolt heads at the other. Such wrenches are very cheap and are worth many times their small cost, especially for fitting nuts where there is not sufficient room to admit the more conventional and larger pattern. The "Starrett" wrench set, which is shown at I, consists of a ratchet handle together with an extension bar and universal joint, a sparkplug socket, a drilling attachment which takes standard square shank drills from 1/8 inch to 1/2 inch in diameter, a double ended screwdriver bit and several adjustments to go with the drilling attachment. Twenty-eight assorted cold drawn steel sockets similar in design to those shown at D, to fit all standard sizes of square and hexagonal headed nuts are also included. The reversible ratchet handle, which may be slipped over the extension bar or the universal joint and which

is also adapted to take the squared end of any one of the sockets is exceptionally useful in permitting, as it does, the instant release of pressure when it is desired to swing the handle back to get another hold on the nut. The socket wrench sets are usually supplied in hard wood or steel cases or in leather bags so that they may be kept together and protected against loss or damage. With a properly selected socket wrench set, either of the ratchet handle or T-handle form, any nut on the engine may be reached and end wrenches will not be necessary.

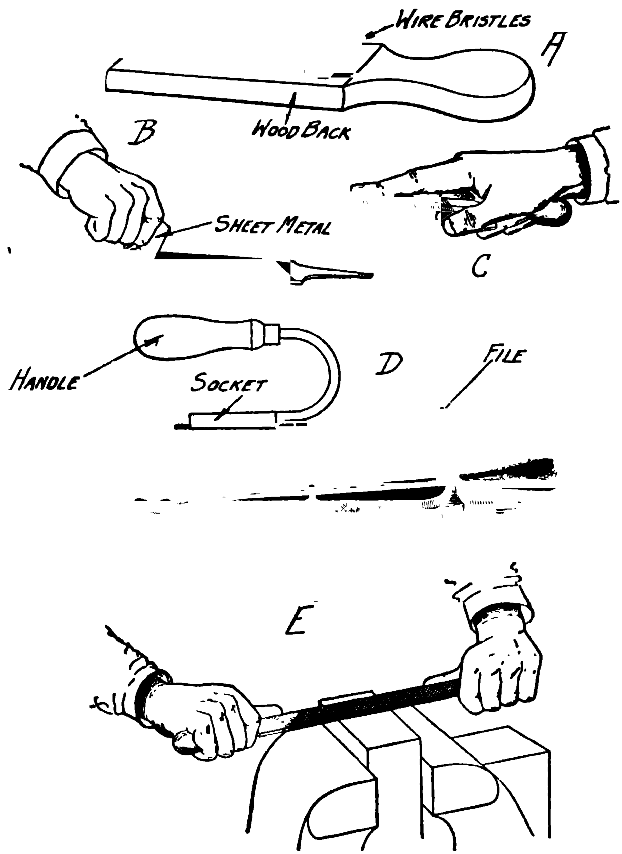


Fig. 832.—Illustrating Use and Care of Files. A—File Cleaning Brush. B—How to Remove Soft Metal from File Teeth. C—Method of Holding Small Flat File to Prevent Springing. D—Handles for Files Used on Flat Surfaces. E—How to Drawfile.

Use and Care of Files.—Mention has been previously made of the importance of providing a complete set of files and suitable handles. These should be in various grades or degrees of fineness and three of each kind should be provided. In the flat and half round files three grades are necessary, one with coarse teeth for roughing, and others with medium and

fine teeth for the finishing cuts. The round or rat tail file is necessary in filing out small holes, the half round for finishing the interior of large ones. Half round files are also well adapted for finishing surfaces of peculiar contour, such as the inside of bearing boxes, connecting rod and main bearing caps, etc. Square files are useful in finishing keyways or cleaning out burred splines, while the triangular section or three-cornered file is of value in cleaning out burred threads and sharp corners. Flat files are used on all plane surfaces.

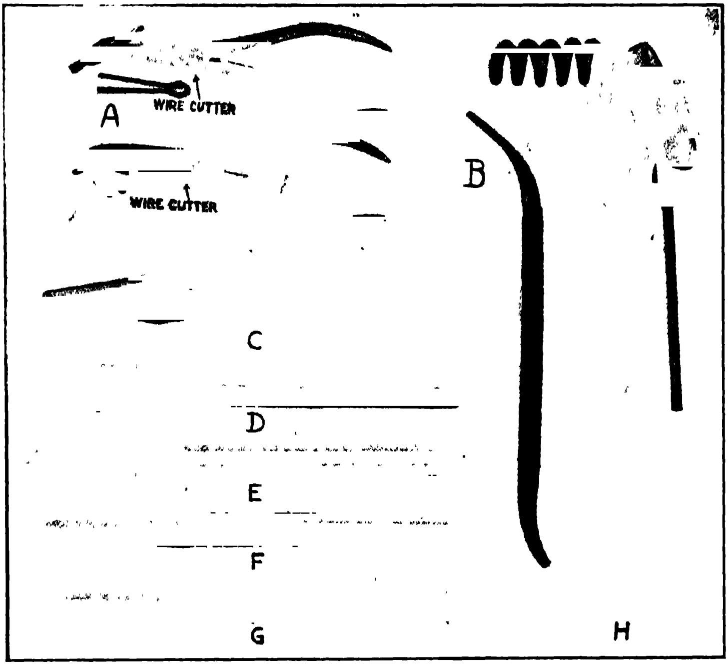


Fig. 833.—Outlining Use of Cotter Pin Pliers at A. B Shows Simple Cotter Pin Extractor. C—Cape Chisel. D—Cutting Chisel. E—Round Point Grooving Chisel. F—Diamond Point Grooving Chisel. G—Center Punch. H—Winder for Small Coil Springs.

The file brush shown at Fig. 832 A, consists of a large number of wire bristles attached to a substantial wood back having a handle of convenient form so that the bristles may be drawn through the interstices between the teeth of the file to remove dirt and grease. If the teeth are filled with pieces of soft metal, such as solder or babbitt, it may be necessary to remove this accumulation with a piece of sheet metal as indicated at Fig. 832 B. The method of holding a file for working on plane surfaces when it is fitted with the regular form of wooden handle is shown at C, while two types of handles enabling the mechanic to use the flat file on plane surfaces of such size that the handle type indicated at C, could not be used on account of interfering with the surface finished are shown at D. The method of using a file when surfaces are finished by draw filing is shown at E. This differs

from the usual method of filing and is only used when surfaces are to be polished and very little metal removed. Files must be handled very carefully as they may remove more metal than required in fitting pieces. Hard pieces cannot be filed and any rough spots can be taken down with fine emery cloth or with a carborundum stone.

Split Pin Removal and Insertion.—One of the most widely used of the locking means to prevent nuts or bolts from becoming loose is the simple split pin, sometimes called a "cotter pin." These can be handled very easily if the special pliers shown at Fig. 833 A, are used. They have a curved jaw that permits of grasping the pin firmly and inserting it in the hole ready to receive it. It is not easy to insert these split pins by other means because the ends are usually spread out and it is hard to enter the pin in the hole. With the cotter pin pliers the ends may be brought close together and as the plier jaws are small the pin may be easily pushed in place. Another use of this plier, also indicated, is to bend over the ends of the split pin in order to prevent it from falling out. To remove these pins a simple curved lever, as shown at Fig. 833 B, is used. This has one end tapering to a point and is intended to be inserted in the eye of the cotter pin, the purchase offered by the handle permitting of ready removal of the pin even after the ends have been closed by the cotter pin pliers.

Complete Chisel Set.—A complete chisel set suitable for repair shop use is also shown at Fig. 833. The type at C is known as a "cape" chisel and has a narrow cutting point and is intended to chip keyways, remove metal out of corners, and for all other work where the broad cutting edge chisel, shown at D, cannot be used. The form with the wide cutting edge is used in chipping, cutting sheet metal, etc. At E, a round nose chisel used in making oil ways is outlined, while a similar tool having a pointed cutting edge and often used for the same purpose is shown at F. The center punch depicted at G, is very useful for marking parts either for identification or for drilling. In addition to the chisels shown, a number of solid punches or drifts resembling very much that shown at E, except that the point is blunt should be provided to drive out taper pins, bolts, rivets, and other fastenings of this nature. These should be provided in the common sizes. A complete set of real value would start at $\frac{1}{8}$ inch and increase by increments of $\frac{1}{32}$ inch up to $\frac{1}{2}$ inch. A simple spring winder is shown at Fig. 833 H, this making it possible for the repairman to wind coil springs, either on the lathe or in the vise. It will handle a number of different sizes of wire and can be set to space the coils as desired.

Hand Drilling Machines.—Drilling machines may be of two kinds, hand or power operated. For drilling small holes in metal it is necessary to run the drill fast, therefore the drill chuck is usually driven by gearing in order to produce high drill speed without turning the handle too fast. A small hand drill is shown at Fig. 834 A, and is commonly termed an "egg beater" by shop men. As will be observed, the chuck spindle is driven by a small bevel pinion, which in turn, is operated by a large bevel gear turned by a crank. The gear ratio is such that one turn of the handle will turn the chuck five or six revolutions. A drill of this design is not suited for drills any larger than one-quarter inch. For use with drills ranging from one-eighth to three-eighths, or even half-inch the hand drill presses shown at

C and D are used. These have a pad at the upper end by which pressure may be exerted with the chest in order to feed the drill into the work, and for this reason they are termed "breast drills." The form at C has compound gearing, the drill chuck being driven by the usual form of bevel pinion in mesh with a larger bevel gear at one end of a countershaft. A small helical spur pinion at the other end of this countershaft receives its motion from a larger gear turned by the hand crank. This arrangement

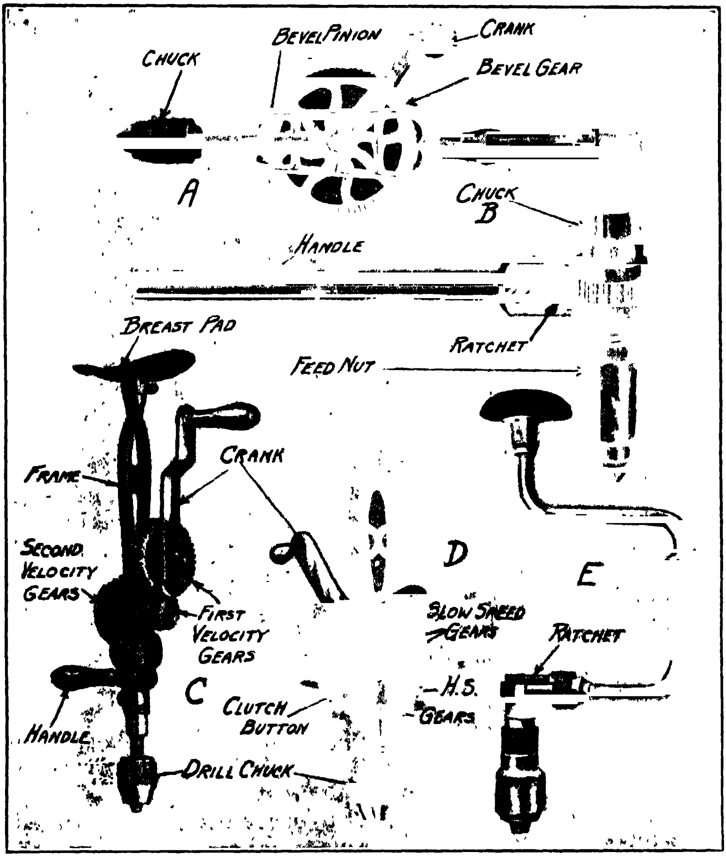


Fig. 834.—Forms of Hand Operated Drilling Machines. A—"Eggbeater" for Small Drills. B—"Old Man" or Ratchet Drill for Heavy Work. C and D—Breast Drills. E—Carpenter's Bitstock for Boring Holes in Wood.

of gearing permits of high spindle speed without the use of large gears, as would be necessary if but two were used. The form at D gives two speeds, one for use with small drills is obtained by engaging the lower bevel pinion with the chuck spindle and driving it by the large ring gear. The slow speed is obtained by shifting the clutch so that the top bevel pinion drives the drill chuck. As this meshes with a gear but slightly larger in diameter, a slow speed of the drill chuck is possible. Breast drills are

provided with a handle screwed into the side of the frame, these are used to steady the drill press. For drilling extremely large holes which are beyond the capacity of the usual form of drill press the ratchet form shown at B, may be used or the bit brace outlined at E. The drills used with either of these have square shanks, whereas those used in the drill presses have round shanks. The bit brace is also used widely in wood work and the form shown is provided with a ratchet by which the bit chuck may be turned through only a portion of a revolution in either direction if desired.

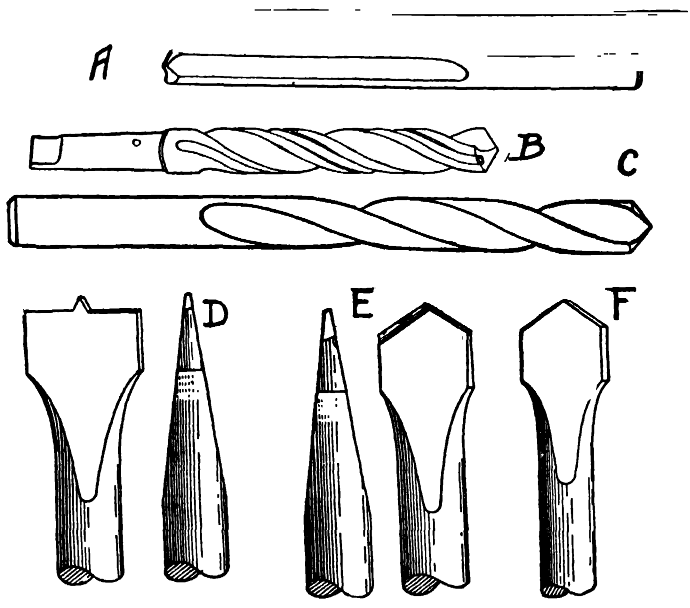


Fig. 835.—Forms of Drills Used in Hand and Power Drilling Machines.

Drills, Reamers, Taps and Dies.—In addition to the larger machine tools which this treatise does not cover and the simple hand tools previously described, an essential item of equipment of any engine or plane repair shop, even in cases where the ordinary machine tools such as lathes, drill presses, etc. are not provided, is a complete outfit of drills, reamers, and threading tools. Drills are of two general classes, the flat and the twist drills. The flat drill has an angle between cutting edges of about 110 degrees and is usually made from special steel commercially known as drill rod. A flat drill cannot be fed into the work very fast because it removes metal by a scraping, rather than a cutting process. The twist drill in its simplest form is cylindrical throughout the entire length and has spiral flutes which are ground off at the end to form the cutting lip and which also serve to carry the metal chips out of the holes. The simplest form of twist drill used is shown at Fig. 835 C, and is known as a "chuck" drill, because it must be placed in a suitable chuck to turn it. A twist drill removes metal

by cutting and it is not necessary to use a heavy feed as the drill will tend to feed itself into the work.

Larger drills than ¾ inch are usually made with a tapered shank as shown at Fig. 835 B. At the end of the taper a tongue is formed which engages with a suitable opening in the collect, as the piece used to support and drive the drill is called. The object of this tongue is to relieve the tapered portion of the drill from the stress of driving by frictional contact alone, as this would not turn the drill positively and the resulting slippage would wear the socket, this depreciation changing the taper and making it unfit for other drills. The tongue is usually proportioned so it is adequate to drive the drill under any condition. A small keyway is provided in the collet into which a tapering key of flat stock may be driven against the end of the tongue to drive the drill from the spindle. A standard taper for drill shanks generally accepted by the machine trade is known as the Morse and is a taper of five-eighths of an inch to the foot. The Brown and Sharp form tapers six-tenths of an inch to the foot. The Brown and Sharp form tapers six-tenths of an inch to the foot. Care must be taken, therefore, when purchasing drills and collets, to make sure that the tapers coincide, as no attempt should be made to run a Morse taper in a Brown and Sharp collet, or vice versa.

Fig. 836.—Useful set of Number Drills, Showing Stand for Keeping These in an Orderly Manner.

Sometimes cylindrical drills have straight flutes, as outlined at Fig. 835 A. Such drills are used with soft metals as lead, aluminum and brass and are of value when the drill is to pass entirely through the work. The trouble with a drill with spiral flutes is that it will tend to draw itself through as the cuting lips break through. This catching of the drill may break it or move the work from its position. With a straight flute drill the cutting action is practically the same as with the flat drill shown at Fig. 835 E and F.

If a drill is employed in boring holes through close-grained, tough metals, as wrought or malleable iron and steel, the operation will be facilitated by lubricating the drill with plenty of lard oil or a solution of soda and water. Either of these materials will effectually remove the heat caused by the friction of the metal removed against the lips of the drill, and the danger of heating the drill to a temperature that will soften it by drawing the temper is minimized. In drilling large or deep holes it is good practice to apply the lubricating medium directly at the drill point. Special drills of the form having a spiral oil tube running in a suitably formed channel, provides communication between the point of the drill and a suitable receiving hole on a drilled shank. The oil is supplied by a pump and its pressure not only promotes positive circulation and removal of heat,

but also assists in keeping the hole free of chips. In drilling steel or wrought iron, lard oil applied to the point of the drill will facilitate the drilling, but this material should never be used with either brass or cast iron.

The sizes of drills to be provided depend upon the nature of the work and the amount of money that can be invested in drills. It is common practice to provide a set of drills, such as shown at Fig. 836, which are carried in a suitable metal stand, these being known as number drills on account of conforming to the wire gauge standards. Number drills do not usually run higher than $\frac{7}{16}$ inch in diameter. Beyond this point drills are usually sold by the diameter. A set of chuck drills, ranging from $\frac{3}{8}$ to $\frac{3}{4}$ inch, advancing by $\frac{1}{32}$ inch, and a set of Morse taper shank drills ranging from $\frac{3}{4}$ to $1\frac{1}{4}$ inches, by increments of $\frac{1}{16}$ inch, will be all that is needed for the most pretentious repair shop, as it is cheaper to bore holes larger than $1\frac{1}{4}$ inches with a boring tool than it is to carry a number of large drills in stock that would be used very seldom, perhaps not enough to justify their cost.

In grinding drills, care must be taken to have the lips of the same length, so that they will form the same angle with the axis. If one lip is longer than the other, as shown in the flat drill at Fig. 835 E, the hole will be larger than the drill size, and all the work of cutting will come upon the longest lip. The drill ends should be symmetrical, as shown at Fig. 835 F.

Types and Use of Reamers.—It is considered very difficult to drill a hole to an exact diameter, but for the most work a variation of a few thousandths of an inch is of no great moment. Where accuracy is necessary, holes must be reamed out to the required size. In reaming, a hole is drilled about $\frac{1}{64}$ inch smaller than is required, and is enlarged with a cutting tool known as the reamer. Reamers are usually of the fluted form shown at Fig. 837 A. Tools of this nature are not designed to remove considerable amounts of metal, but are intended to augment the diameter of the drill hole by only a small fraction of an inch. Reamers are tapered slightly at the point in order that they will enter the hole easily, but the greater portion of the fluted part is straight, all cutting edges being parallel. Hand reamers are made in either the straight or taper forms, that at A, Fig. 837, being straight, while B has tapering flutes. They are intended to be turned by a wrench similar to that employed in turning a tap, as shown at Fig. 839 C. The reamer shown at Fig. 170 C is a hand reamer. The form at D has spiral flutes similar to a twist drill, and as it is provided with a taper shank it is intended to be turned by power through the medium of a suitable collet.

As the solid reamers become reduced in size when sharpened, various forms of inserted blade reamers have been designed. One of these is shown at E, and as the cutting surfaces become reduced in diameter it is possible to replace the worn blades with others of proper size. Expanding reamers are of the form shown at F. These have a bolt passing through that fits into a tapering hole in the interior of the split reamer portion of the tool. If the hole is to be enlarged a few thousandths of an inch, it is possible to draw up on the nut just above the squared end of the shank, and by drawing the tapering wedge farther into the reamer body, the cutting portion will be expanded and will cut a larger hole.

Reamers must be very carefully sharpened or there will be a tendency toward chattering with a consequent production of a rough surface. There are several methods of preventing this chattering, one being to separate the cutting edges by irregular spaces, while the most common method, and that to be preferred on machine reamers, is to use spiral flutes, as shown at Fig. 837 D. Special taper reamers are made to conform to the various taper pin sizes which are sometimes used in holding parts together in an engine. A taper of 1/16 inch per foot is intended for holes where a pin, once driven in, is to remain in place. When it is desired that the pin be driven out, the taper is made steeper, generally 1/4 inch per foot, which is the standard taper used on taper pins.

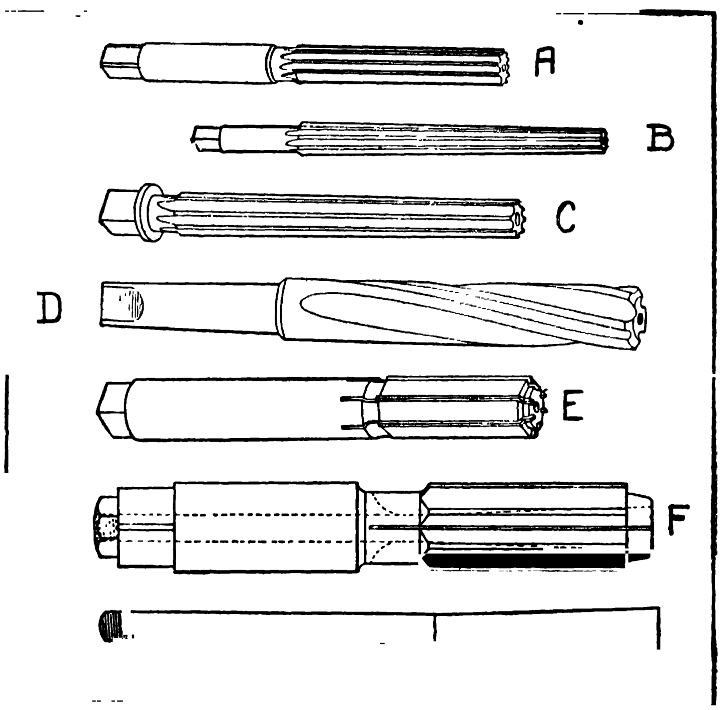


Fig. 837.—Standard Forms of Hand and Machine Reamers.

Use of Taps and Dies.—When threads are to be cut in a small hole, it will be apparent that it will be difficult to perform this operation economically on a lathe, therefore when internal threading is called for, a simple device known as a "tap" is used. There are many styles of taps, all conforming to different standards. Some are for metric or foreign threads, some conform to the American standards, while others are used for pipe and tubing. Hand taps are the form most used in repail shops, these being outlined at Fig. 838 A and B. They are usually sold in sets of three, known respectively as taper, plug, and bottoming. The taper tap is the one first put

into the hole, and is then followed by the plug tap which cuts the threads deeper. If it is imperative that the thread should be full size clear to the bottom of the hole, the third tap of the set, which is straight-sided, is used. It would be difficult to start a bottoming tap into a hole because it would be larger in diameter at its point than the hole. The taper tap, as shown at A, Fig. 838, has a portion of the cutting lands ground away at the point in order that it will enter the hole and some taps have even a more pronounced taper than is shown in the illustration. The manipulation of a tap is not hard, as it does not need to be forced into the work, as the thread will draw it into the hole as the tap is turned. The tapering of a tap is done so that no one thread is called upon to remove all of the metal, as for about half way up the length of the tap each succeeding thread is cut a little larger by the cutting edge until the full thread enters the hole. Care must be taken to always enter a tap straight in order to have the threads at correct angles to the surface.

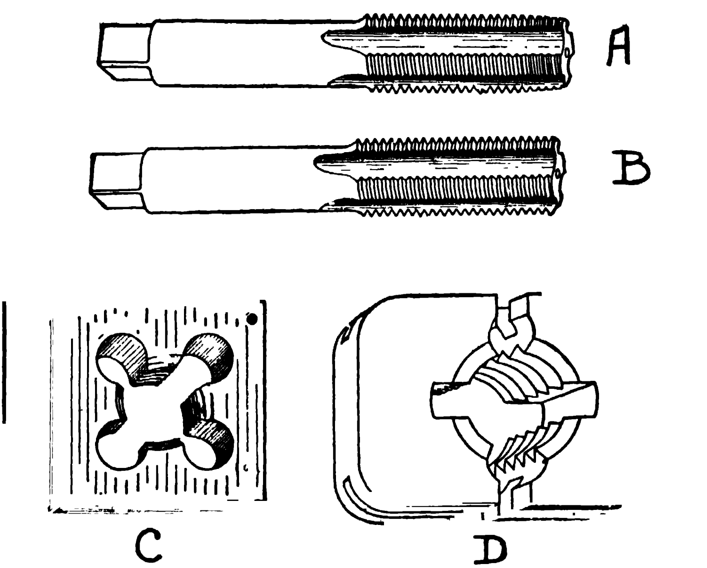


Fig. 838.—Taps and Dies for Thread Cutting.

In cutting external threads on small rods or on small pieces, such as bolts and studs, it is not always economical or possible to do this work in the lathe, especially in repair work. Dies are used to cut threads on pieces that are to be placed in tapped holes that have been threaded by the corresponding size of tap. Dies for small work are often made solid, as shown at Fig. 838 C, but solid dies are usually limited to sizes below ½ inch. Sometimes the solid die is cylindrical in shape, with a slot through one side which enables one to obtain a slight degree of adjustment by squeezing the slotted portion together with an adjusting screw but the

degree of variation obtainable by this method is slight. Large dies, or the sizes over ½ inch, are usually made in two pieces in order that the halves may be closed up or brought nearer together. The advantage of this form of die is that either of the two pieces may be easily sharpened, and as it may be adjusted very easily the thread may be cut by easy stages. For example, the die may be adjusted to cut large, which will produce a shallow thread that will act as an accurate guide when the die is closed up and a deeper thread cut. Less effort will be required.

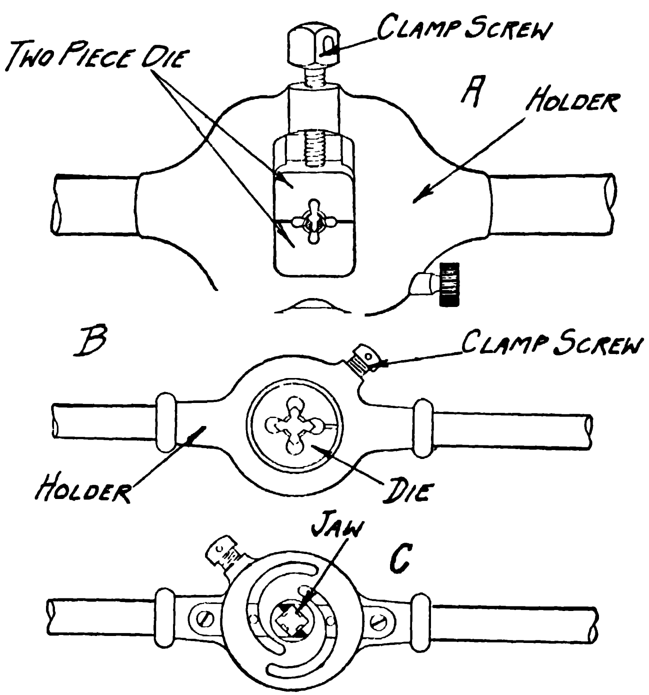


Fig. 839.—Showing Holders for One and Two-Piece Thread Cutting Dies.

A common form of die holder for an adjustable die is shown at Fig. 839 A. As will be apparent, it consists of a central body portion having guide members to keep the die pieces from falling out and levers at each end in order to permit the operator to exert sufficient force to remove the metal. The method of adjusting the depths of thread with a clamp screw when a two-piece die is employed is also clearly outlined. The diestock shown at B is used for the smaller dies of the one-piece pattern, having a slot in order that they may be closed up slightly by the clamp screw. The reverse side of the diestock shown at B is outlined below it, and the guide pieces, which may be easily moved in or out, according to the size of the piece to be threaded by means of eccentrically disposed semi-circular slots in the adjustment plate, are shown. These movable guide members have small

pins let into their surface which engage the slots, and they may be moved in or out, as desired, according to the position of the adjusting plate. The use of the guide pieces makes for accurate positioning or centering of the rod to be threaded. Dies are usually sold in sets, and are commonly furnished as a portion of a complete outfit such as outlined at Fig. 840. That shown has two sizes of diestock, a tap wrench, eight assorted dies, eight assorted taps, and a small screwdriver for adjusting the die. An aviation engine repair shop should be provided with three different sets of taps and dies, as three different standards for the bolts and nuts are used in fastening automotive components. These are the American; metric (used on foreign engines), and the S. A. E. aeronautic standard threads. A set of pipe dies and taps will also be found useful in general shop maintenance work and for building various appliances such as engine stands, etc., of piping.

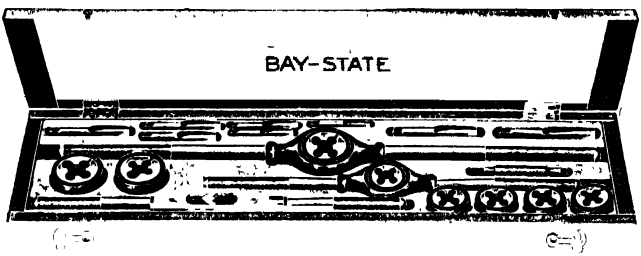


Fig. 840.—Useful Outfit of Taps and Dies for the Engine Repair Shop.

Measuring Tools.—The tool outfit of the machinist or the mechanic who aspires to do machine work must include a number of measuring tools which are not needed by the floor man or one who merely assembles and takes apart the finished pieces. The machinist who must convert raw material into finished products requires a number of measuring tools, some of which are used for taking only approximate measurements, such as calipers and scales, while others are intended to take very accurate measurements, such as the Vernier and the micrometer. A number of common forms of calipers are shown at Fig. 841. These are known as inside or outside calipers, depending upon the measurements they are intended to take. That at A is an inside caliper, consisting of two legs, A and D, and a gauging piece, B, which can be locked to leg A, or released from the member by the screw, C. The object of this construction is to permit of measurements being taken at the bottom of a two diameter hole, where the point to be measured is of larger diameter than the portion of the hole through which the calipers entered. It will be apparent that the legs A and D must be brought close together to pass through the smaller holes. This may be done without losing the setting, as the guide bar B will remain in one position as determined by the size of the hole to be measured, while the leg A may be swung in to clear the obstruction as the calipers are lifted

out. When it is desired to ascertain the measurements the leg A is pushed back into place into the slotted portion of the guide B, and locked by the clamp screw C. A tool of this form is known as an internal transfer caliper.

The form of caliper shown at B is an outside caliper. Those at C and D are special forms for inside and outside work, the former being used, if desired, as a divider, while the latter may be employed for measuring the walls of tubing. The calipers at E are simple forms, having a friction joint to distinguish them from the spring calipers shown at B, C and D. In order to permit of ready adjustment of a spring caliper, a split nut as shown at G is sometimes used. A solid nut caliper can only be adjusted by screwing the nut in or out on the screw, which may be a tedious process if the caliper is to be set from one extreme to the other several times in succession. With a slip nut as shown at G it is possible to slip it from one end of the thread to the other without turning it, and of locking it in place at any desired point by simply allowing the caliper leg to come in contact with it. The method of adjusting a spring caliper is shown at Fig. 841 H.

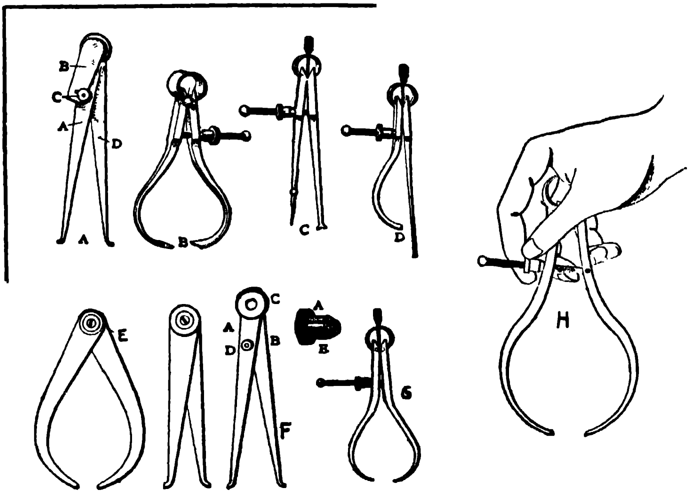


Fig. 841.—Common Forms of Inside and Outside Caliper Useful for Taking and Transferring Measurements.

Rules and Scales.—Among the most common of the machinst's tools are those used for linear measurements. The usual forms are shown in group, Fig. 842. The most common tool, which is widely known, is the carpenter's folding two-foot or six-foot rule or the yardstick. While these are very convenient for taking measurements where great accuracy is not required, the engine mechanic must work much more accurately than the carpenter, and the standard steel scale which is shown at D, is a popular tool for the machinist or engine man. The steel scale is in reality a graduated straight edge and forms an important part of varions measuring tools. These are made of high grade steel and vary from one to 48 inches in length. They are carefully hardened in order to preserve the graduations,

and all surfaces and edges are accurately ground to insure absolute parallelism. The graduations on the high grade scales are produced with a special device known as a dividing engine, but on cheaper scales, etching suffices to provide a fairly accurate graduation. The steel scales may be very thin and flexible, or may be about an eighth of an inch thick on the twelve-inch size, which is that commonly used with combination squares,

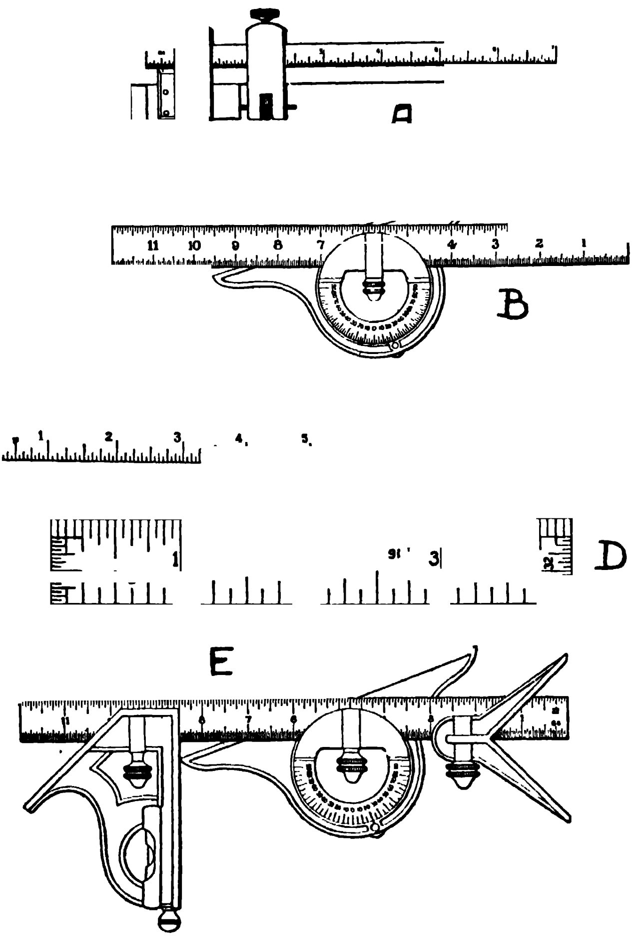


Fig. 842.—Measuring Appliances for the Aero Machinist and Engine Repair Mechanic.

protractors and other tools of that nature. The repairman's scale should be graduated both with the English system, in which the inches are divided into eighths, sixteenths, 32d's and 64th's, and also in the metric system, divided into millimeters and centimeters. Some machinists use scales graduated in tenths, twentieths, 50th's and 100th's. This is not as good

a system of graduation as the more conventional one first described as dimensions are either in inch units or metric units.

Some steel scales are provided with a slot or groove cut the entire length on one side and about the center of the scales. This permits the attachment of various fittings such as the protractor head, which enables the machinist to measure angles, or in addition the heads convert the scale into a square or a tool permitting the accurate bisecting of pieces of circular section. Two scales are sometimes joined together to form a right angle, such as shown at Fig. 842 C. This is known as a square and is very valuable in ascertaining the truth of vertical pieces that are supposed to form a right angle with a base piece.

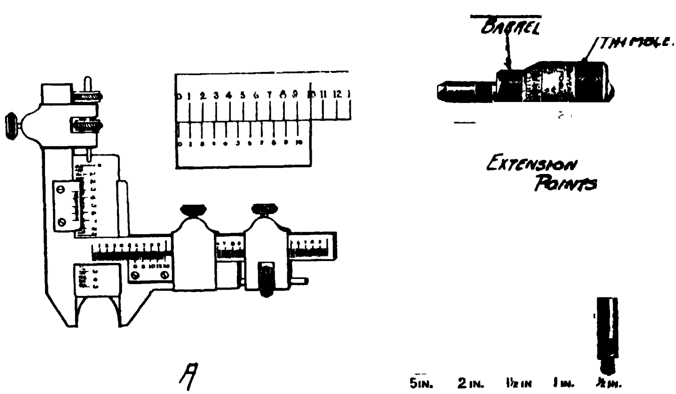


Fig. 843.—At Left, Special Form of Vernier Caliper for Measuring Gear Teeth; at Right, Micrometer and Extension Points for Making Accurate Internal Measurements.

Vernier and Its Use.—The Vernier is a device for reading finer divisions on a scale than those into which the scale is divided. Sixty-fourths of an inch are about the finest division that can be read accurately with the naked eye. When fine work is necessary a Vernier is employed. This consists essentially of two rules so graduated that the true scale has each inch divided into ten equal parts, the upper or Vernier portion has ten divisions occupying the same space as nine of the divisions of the true scale. It is evident, therefore, that of the divisions of the Vernier is equal to nine-tenths of one of those on the true scale. If the Vernier scale is moved to the right so that the graduations marked "1" shall coincide, it will have moved one-tenth of a division on the scale or one-hundredth of an inch. When the graduations numbered five coincide the Vernier will have moved five-hundredths of an inch; when the lines marked zero and ten coincide, the Vernier will have moved nine-hundredths of an inch, and when ten on the Vernier comes opposite ten on the scales, the upper rule will have moved ten-hundredths of an inch, or the whole of one division on the scale. By this means the scale, though it may be graduated only to tenths of an inch, may be accurately set at points with positions expressed in hundredths of an inch. When graduated to read in thousandths, the true

scale is divided into fifty parts and the Vernier into twenty parts. Each division of the Vernier is therefore equal to nineteen-twentieths of one of the true scale. If the Vernier be moved so the lines of the first division coincide, it will have moved one-twentieth of one-fiftieth, or .001 inch. The Vernier principle can be readily grasped by studying the section of the Vernier scale and true scale shown at Fig. 843 A.

The caliper scale which is shown at Fig. 842 A, permits of taking the over-all dimension of any parts that will go between the jaws. This scale can be adjusted very accurately by means of a fine thread screw attached to a movable jaw and the divisions may be divided by eye into two parts if one sixty-fourth is the smallest of the divisions. A line is indicated on the movable jaw and coincides with the graduations on the scale. As will be apparent, if the line does not coincide exactly with one of the graduations it will be at some point between the lines and the true measurement may be approximated without trouble.

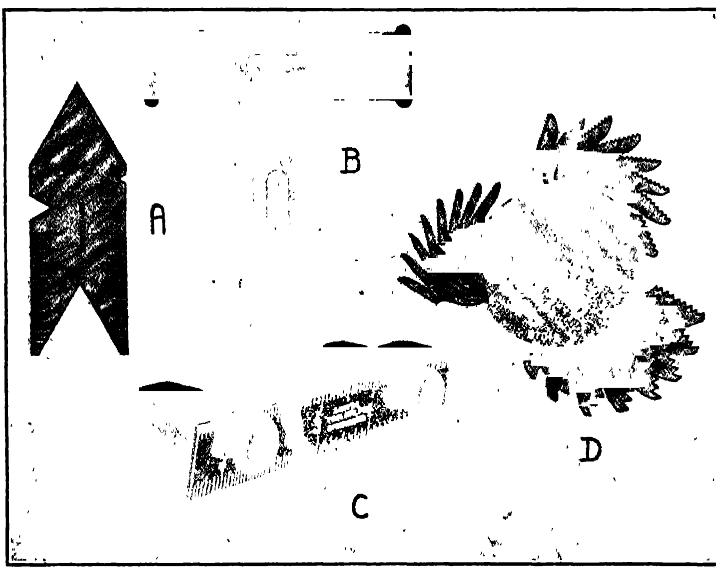


Fig. 844.—Measuring Appliances of Value in Airplane Engine Repair Work.

A group of various other measuring tools of value to the machinist is shown at Fig. 844. The small scale at A is termed a "center gauge," because it can be used to test the truth of the taper of either a male or female lathe center. The two smaller nicks, or v's, indicate the shape of a standard thread, and may be used as a guide for grinding the point of a thread-cutting tool. The cross level which is shown at B is of marked utility in erecting, as it will indicate absolutely if the piece it is used to test is level. It will indicate if the piece is level along its width as well as its length.

A very simple attachment for use with a scale that enables the machinist to scribe lines along the length of a cylindrical piece is shown at Fig. 844 C. These are merely small wedge-shaped clamps having an angular face

to rest upon the bars. The thread pitch gauge which is shown at Fig. 844 D, is an excellent pocket tool for the mechanic, as it is often necessary to determine without loss of time the pitch of the thread on a bolt or in a nut. This consists of a number of leaves having serrations on one edge corresponding to the standard thread it is to be used in measuring. The tool shown gives all pitches up to 48 threads per inch. The leaves may be folded in out of the way when not in use, and their shape admits of their being used in any position without the remainder of the set interfering with the one in use. The fine pitch gauges have slim, tapering leaves of the correct shape to be used in finding the pitch of small nuts. As the tool is round when the leaves are folded back out of the way, it is an excellent pocket tool, as there are no sharp corners to wear out the pocket. Practical application of a Vernier having measuring heads of special form for measuring gear teeth is shown at Fig. 843 A. As the action of this tool has been previously explained, it will not be necessary to describe it further. Another useful measuring appliance is a set of "feeler" gauges which are made of spring steel in various thicknesses as expressed in .001 inch (one thousandth of an inch) increments. These are in the form of tongues or leaves riveted at one end in a handle, just as a knife blade is, so that one or more of the thin tongues may be used to measure with. Such gauges are of great value in determining piston ring gaps, magneto breaks, valve stem clearances, etc. Dial indicators on special measuring heads are valuable for testing cylinder bores, etc., and are an important item of shop equipment.

Micrometer Calipers and Their Use.—Where great accuracy is necessary in taking measurements the micrometer caliper, which in the simple form will measure easily .001 inch (one-thousandth part of an inch) and when fitted with a Vernier that will measure .0001 inch (one ten-thousandth part of an inch), is used. The micrometer may be of the caliper form for measuring outside diameters or it may be of the form shown at Fig. 176 B, for measuring internal diameters. The operation of both forms is identical except that the internal micrometer is placed inside of the bore to be measured while the external form is used just the same as a caliper. The form outlined will measure from one and one-half to six and a half inches as extension points are provided to increase the range of the instrument. The screw has a movement of one-half inch and a hardened anvil is placed in the end of the thimble in order to prevent undue wear at that point. The extension points or rods are accurately made in standard lengths and are screwed into the body of the instrument instead of being pushed in, this insuring firmness and accuracy. Two forms of micrometers for external measurements are shown at Fig. 845. The top one is graduated to read in thousandths of an inch, while the lower one is graduated to indicate hundredths of a millimeter. The mechanical principle involved in the construction of a micrometer is that of a screw free to move in a fixed nut. An opening to receive the work to be measured is provided by the backward movement of the thimble which turns the screw and the size of the opening is indicated by the graduations on the barrel.

The article to be measured is placed between the anvil and spindle, the frame being held stationary while the thimble is revolved by the thumb and

finger. The pitch of the screw thread on the concealed part of the spindle is 40 to an inch. One complete revolution of the spindle, therefore, moves it longitudinally one-fortieth, or twenty-five thousandths of an inch. As will be evident from the development of the scale on the barrel of the inch micrometer, the sleeve is marked with forty lines to the inch, each of these lines indicating twenty-five thousandths. The thimble has a beveled edge which is graduated into twenty-five parts. When the instrument is closed

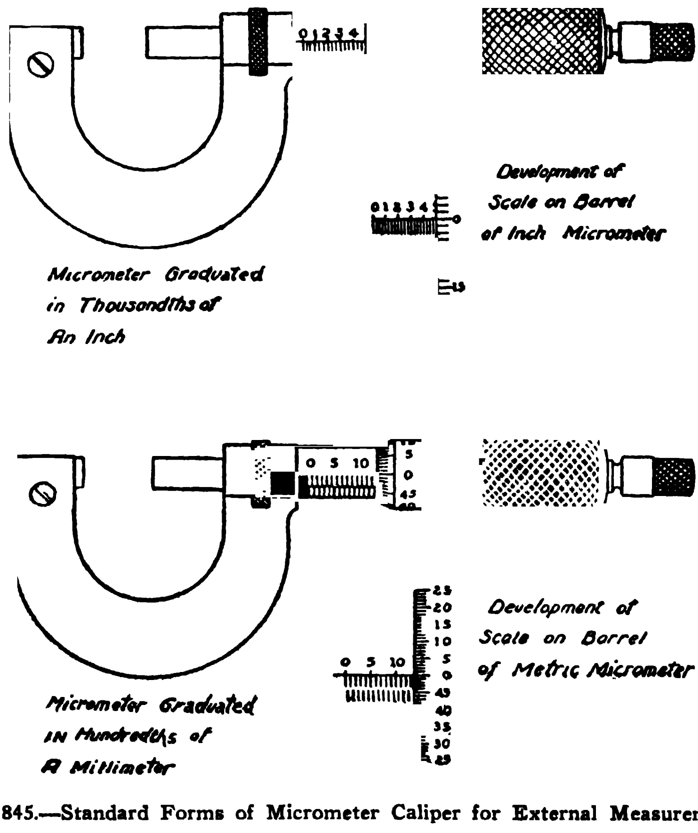


Fig. 845.—Standard Forms of Micrometer Caliper for External Measurements.

the graduation on the beveled edge of the thimble marked 0 should correspond to the 0 line on the barrel. If the micrometer is rotated one full turn the opening between the spindle and anvil will be .025 inch. If the thimble is turned only one graduation, or one twenty-fifth of a revolution, the opening between the spindle and anvil will be increased only by .001 inch (one-thousandth of an inch).

As many of the dimensions of the airplane engine parts, especially of those of foreign manufacture or such parts as ball and roller bearings, are based on the metric system, the competent repairman should possess

both inch and metric micrometers in order to avoid continual reference to a table of metric equivalents. With a metric micrometer there are fifty graduations on the barrel, these representing .01 of a millimeter, or approximately .004 inch. One full turn of the barrel means an increase of half a millimeter, or .50 millimeter (fifty one-hundredths). As it takes two turns to augment the space between the anvil and the stem by increments of one millimeter, it will be evident that it would not be difficult to divide the spaces on the metric micrometer thimble in halves by the eye, and thus the average workman can measure to .0002 inch plus or minus without difficulty. As set in the illustration, the metric micrometers show a space of 13.5 millimeters, or about one millimeter more than half an inch. The inch micrometer shown is set to five-tenths or five hundred one-thousandths or one-half inch. A little study of the foregoing matter will make it easy to understand the action of either the inch or metric micrometer.

Both of the micrometers shown have a small knurled knob at the end of the barrel. This controls the ratchet stop, which is a device that permits a ratchet to slip by a pawl when more than a certain amount of pressure is applied, thereby preventing the measuring spindle from turning further and perhaps springing the instrument. A simple rule than can be easily memorized for reading the inch micrometer is to multiply the number of vertical divisions on the sleeve by 25 and add to that the number of divisions on the bevel of the thimble reading from the zero to the line which coincides with the horizontal line on the sleeve. For example: if there are ten divisions visible on the sleeve, multiply this number by 25, then add the number of divisions shown on the bevel of the thimble, which is ten. The micrometer is therefore opened 10×25 equals 250 plus 10 equals 260 thousandths.

Micrometers are made in many sizes, ranging from those having a maximum opening of one inch to special large forms that will measure 40 or more inches. While it is not to be expected that the repairman will have use for the big sizes, if a caliper having a maximum opening of six inches is provided with a number of extension rods enabling one to measure smaller objects, practically all of the measuring needed in repairing engine parts can be made accurately. Two or three smaller micrometers having a maximum range of two or three inches will also be found valuable, as most of the measurements will be made with these tools which will be much easier to handle than the larger sizes.

Hints for Care of Tools.—Protect all edge tools. Keep all edge tools sharp. Never let a tool become dull. If you dull a tool by using, sharpen before returning it to place. In sharpening an edge tool, do not blunt it. Grind an angle and keep it until the tool becomes sharp. If you round off an edge tool, you ruin it. Do not use a file like a hacksaw, as most files are made to cut on the forward stroke only. Keep files in a case where they do not rub against each other. Keep files free from oil and grease. When using a file always put a handle on it. Have a file cleaner handy and use it often. For a fine finish on steel, do not use a file; use an oilstone. Do not keep soldering acid near tools, or handle tools after using acid without first washing your hands. Keep a piece or two of charcoal in your toolbox to prevent moisture and consequent rusting of tools,

Check your tools each evening before quitting. Have your list of tools pasted in the top of your tool chest. Do not expect to drill a true hole with a dull bit. Keep bits sharp and in a case. Do not use steel hammer on metal parts. Use a lead, brass or rawhide hammer. Oil your tools often in rainy or wet weather. Do not keep sulphur or salt near your tools. Always oil the steel tape before putting away. Do not use a monkey-wrench as a hammer. Do not use a screwdriver as a punch or drift. Do not use pliers on nuts. Do not use a 24-inch monkey-wrench on a ¼ inch nut. Keep your fine measuring tools in a case.

Do not hold work that is being heated with a torch with a pair of pliers. Use regular tongs. Do not use ordinary cutting pliers to cut piano wire. Use regular nippers furnished for this. Do not use an end wrench on a nut unless it fits it properly. Do not use a socket wrench on a nut unless it fits it properly. In using taps and dies, use plenty of lard oil on the work and be careful in backing up the tap or die. Always read the instructions furnished by manufacturer. In cutting large heavy stock it is better to take more than one cut. Always clean taps and dies before putting them away. In using a tap always be sure that the right sized hole has been drilled. Do not use a Stillson wrench on nuts. In using an oilstone do not sharpen your tools on one place only but use its full length. Always keep a brass drift in your tool chest. Always keep the cutting edge of your saw well protected. In packing tool chest for shipment, pack all tools so they cannot shift in box. Each mechanic is advised to keep a memorandum book in his possession in which he may record such notes as may be considered useful to him.

Typical Tool Outfits.—The equipment of tools necessary for repairing airplane engines depends entirely upon the type of the powerplant and while the common hand tools can be used on all forms, the work is always facilitated by having special tools adapted for reaching the nuts and screws that would be hard to reach otherwise. Special spanners and socket wrenches are very desirable. Then again, the nature of the work to be performed must be taken into consideration. Rebuilding or overhauling an engine calls for considerably more tools than are furnished for making field repairs or minor adjustments. A complete set of tools that was supplied to men working on Curtiss OX2 engines and JN4 training biplanes at Hazlehurst Field, Mineola, L. I., during the World War is shown at Fig. 846. The tools are placed in a special box provided with a hinged cover and are arranged in the systematic manner outlined. The various tools and supplies shown are:—A, hacksaw blades; B, special socket wrenches for engine bolts and nuts; C, ball pein hammers, four sizes; D, five assorted sizes of screwdrivers ranging from very long for heavy work to short and small for fine work; E, seven pairs of pliers including combination in three sizes, two pairs of cutting pliers and one round nose; F, two split pin extractors and spreaders; G, wrench set including three adjustable monkey wrenches, one Stillson or pipe wrench, five sizes adjustable end wrenches and ten double end S wrenches; H, set of files, including flat, three cornered and half round; I, file brush; J, chisel and drift pin; K, three small punches or drifts; L, hacksaw frame; M, soldering copper; N, special spanners for propeller retaining nuts; O, special spanners; P, socket wrenches, long

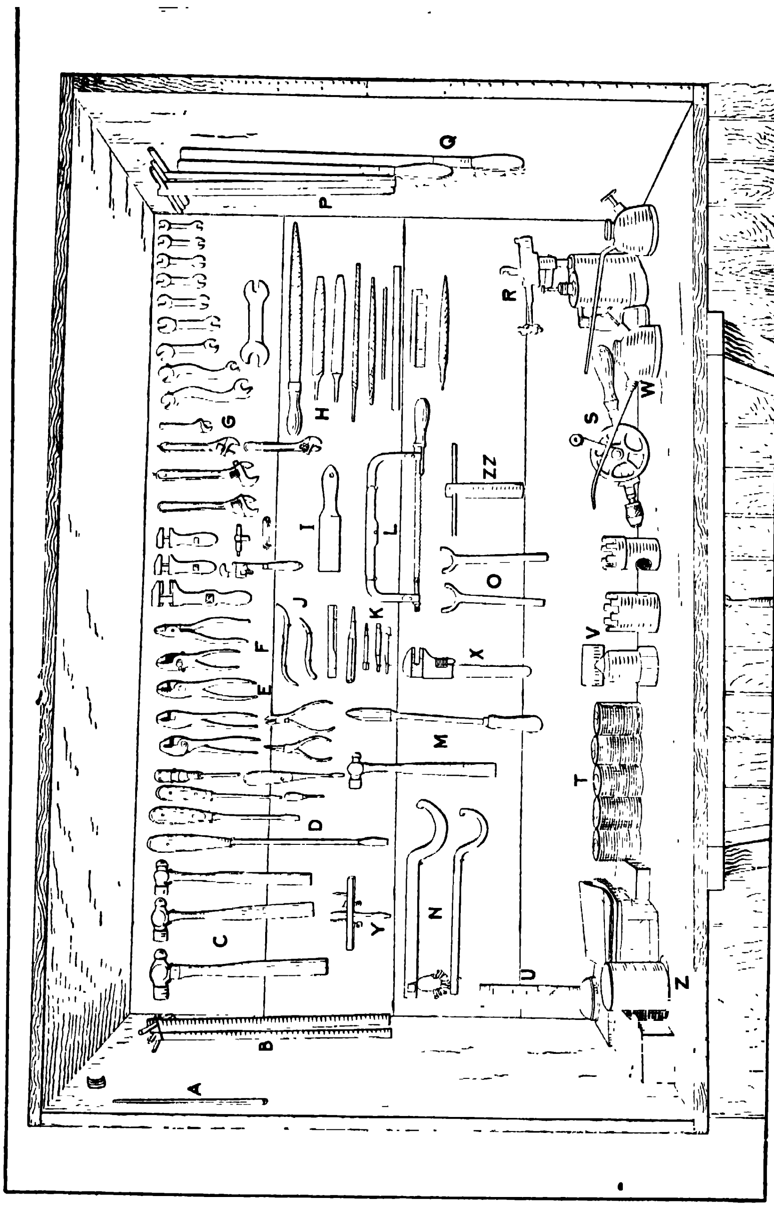


Fig. 846.—Special Tool Outfit for Maintaining Curtiss OX Series Motors Used in Early JN4 Training Biplane and Still Used in Various Commercial Types.

handle; Q, long handle, stiff bristle brushes for cleaning motor; R, gasoline blow torch; S, hand drill; T, spools of safety wire; U, flash lamp; V, special puller and castle wrenches; W, oil can; X, large adjustable monkey wrench; Y, washer and gasket cutter; Z, ball of heavy twine. In addition to the tools, various supplies, such as soldering acid, solder, shellac, valve grinding compound, bolts and nuts, split pins, washers, wood screws, etc., are provided.

The special tools and fixtures recommended by the Hall-Scott Company for work on their engines and used at flying fields where this engine was used in standard training planes are clearly shown at Fig. 847. All tools are numbered and their uses may be clearly understood by reference to the illustration and explantory list given. While both of these engines are now obsolete, the outfits shown may be considered of value as a guide for the selection of other outfits adapted for engines of modern design. Various tools for modern engines are illustrated in other portions of this treatise.

SPECIAL HALL-SCOTT TOOLS

NO.	TOOL
1	Engine hoisting hook, 6-cyl.—Hook under camshaft housing, when hoisting engine.
2	Engine hoisting hook, 4-cyl.—Hook under camshaft housing, when hoisting engine.
3	Water plug wrench—For use on water plugs on top and end of cylinders.
4	Vertical shaft flange puller—For pulling lower pinion shaft flange from shaft. (Used on A-5 and A-7 engines only)
5	Oil gun—For general lubrication use.
6	Magneto gear puller—For pulling magneto gears from magneto shaft.
7	Socket wrench, 1/4" A L A.M.—For use on bolts and nuts on crankcases.
8	Socket wrench, 1/4" A.L.A.M —For use on crankcases and magneto gear housings.
9	Socket wrench, 1/4" A L A M.—For use on magneto gear housings.
10	Socket wrench, 3/8" standard—For bolts and nuts which fasten magnetos to crankcase.
11	Socket wrench, 1/4" A.L.A M.—For use on magneto gear housings.
12	Vertical shaft gear puller—For removing water pump and magneto drive gear.
13	Brace and facing cutter—For facing lugs on cylinders for cylinder hold down stud washers.
14	Handle for brace—Use with brace.
15	Valve grinding brace—For grinding in valves.
16	Socket wrench base, 3/8" A.L.A.M —For thrust bearing cap screws.
17	Brace and facing cutter, 5/16" A L.A.M.—For facing lugs on rocker arm covers.
18	Valve grinding screwdriver—For grinding in valves.
19	Valve spring tool—For putting on and taking off valve springs.
20	Block valve spring tool—For use with valve spring tool.
21	Socket wrench, 5/8" A.L A M.—For main bearing nuts.
22	Socket wrench, 1/4" A.L.A.M.—For use on camshaft housing.
23	Socket wrench, 5/16" A.L.A M.—For camshaft housing hold down stud nuts.
24	Socket wrench, 1/2" A.L.A.M.—For cylinder hold down stud nuts.
25	Socket wrench, 5/16" A.L.A.M.—For carburetor and water pump bolts and nuts.
26	Socket wrench, 5/16" A.L.A M.—For carburetor and water pump bolts and nuts
27	Socket wrench—For use on carburetor jets.
28	Magneto screwdriver—For general magneto use.
29	Brass bar, 1" diameter x 7" long—For driving piston pins from pistons.
30	Hack saw—For general use.
31	Oil can—For camshaft housing lubrication.
32	Gasoline or distillate can—For priming or other use.
33	Oil can—For magneto gear lubrication.
34	Shellac can—For rubber hose connections and gaskets.
35	Magneto cleaner—For use on magnetos.
36	Clamps—For holding cylinder hold down studs, when fitting main bearings.

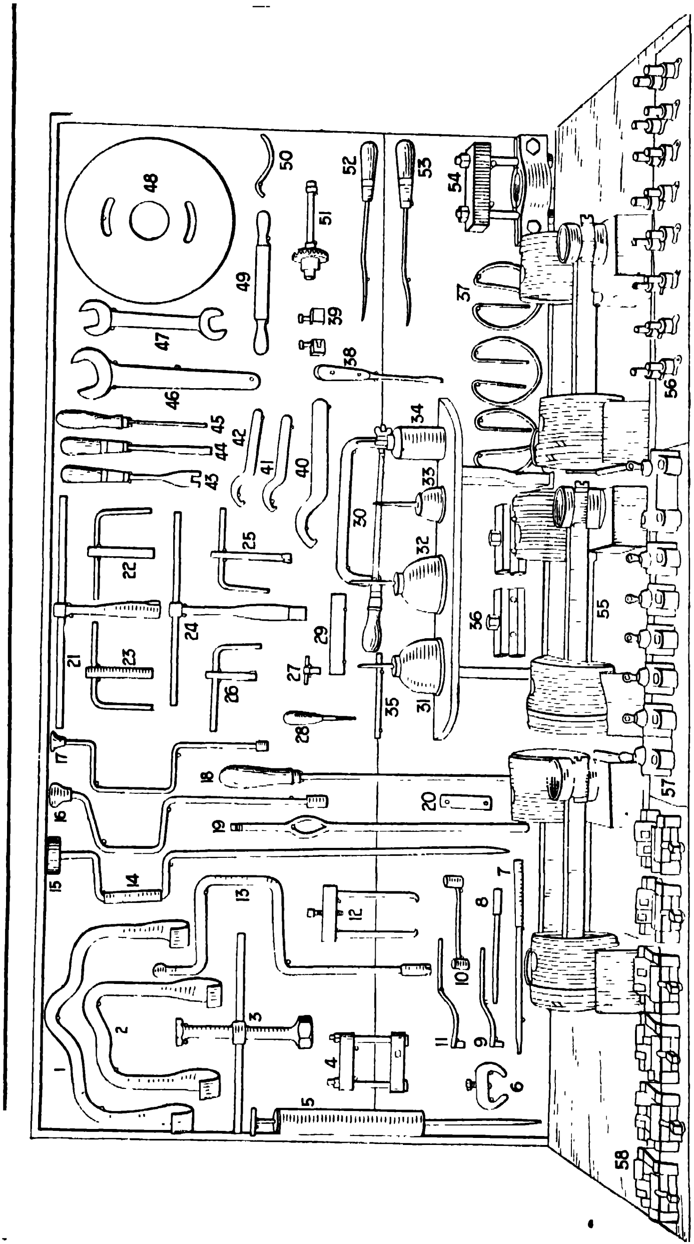


Fig. 847.—Outfit of Special Tools and Appliances to Facilitate Overhauling Work on Hall-Scott Airplane Engines May be Used as a Guide in Selecting Tools for More Modern Engines.

SPECIAL HALL-SCOTT TOOLS—*Continued*

NO.	TOOL
37	Piston guards—For use in pistons, when out of engine, to protect them.
38	Screwdriver—For general use.
39	Vertical shaft clamps—For clamping vertical shaft flanges, when timing engine.
40	Thrust adjusting nut wrench—For adjusting propeller thrust bearing
41	Stuffiing box spanner wrench—For adjusting stuffing box nut on vertical shaft.
42	Water pump spanner wrench—For adjusting water pump stuffing nut.
43	Wrench—For use on cylinder relief cocks and cylinder priming cocks.
44	Hose clamp wrench—For use on hose clamps.
45	Scraper—For cleaning piston ring grooves on pistons.
46	Crankshaft nut wrench—For adjusting crankshaft nut.
47	Sparkplug wrench—For putting in and taking out sparkplugs in cylinders
48	Timing disc (single disc)—For use on crankshaft to time engine Specify type motor disc should be made for If double disc is required, specify the two types of motors the disc is to be made for. Double disc.
49	Main bearing scraper—For scraping in bearings
50	Cylinder carbon scraper—For removing carbon from heads of cylinders.
51	Valve seating tool—For seating valves in cylinder heads.
52	Scraper, small—For general bearing use.
53	Scraper, large—For general bearing use
54	Crankshaft flange puller—For pulling crankshaft flange from crankshaft.
55	Piston and connecting rod racks
56	Main bearing stud nuts and shim rack.
57	Main bearing board rack
58	Rocker arm and cover rack.

The tool requirements of each engine varies according to its construction and the special tools, such as gear pullers, sockets and spanners, etc., depend entirely upon the design of the parts one must remove. Tools may be devised that are universal in their nature for general shop use, as in the service station of the airport that will cater to a variety of engines. Each engine builder sends out a complete kit of tools with each engine to permit of the ordinary operations of overhauling and field work and all are ready to supply those special tools peculiarly adapted to their engines to any shop handling a number of their engines at very moderate prices. The writer strongly urges the executive in charge of engine repairs to secure a complete equipment because airplane engine parts are expensive and as they are more lightly constructed than automobile engine parts, operations with ordinary tools that would not injure auto engine parts may result in serious distortion of aviation engine parts. The cost of replacing a few damaged parts will easily pay for special tools to remove them without damage.

Napier-Lion Engine Kit.—As an example of the tools furnished in a modern standard kit, the reader is referred to Fig. 848, which shows the outfit supplied with each Napier-Lion engine. As compared with earlier tool kits there are certain alterations, some tools now being omitted or superseded, and others added. It should be noted that the tool kits may be modified from time to time as considered necessary.

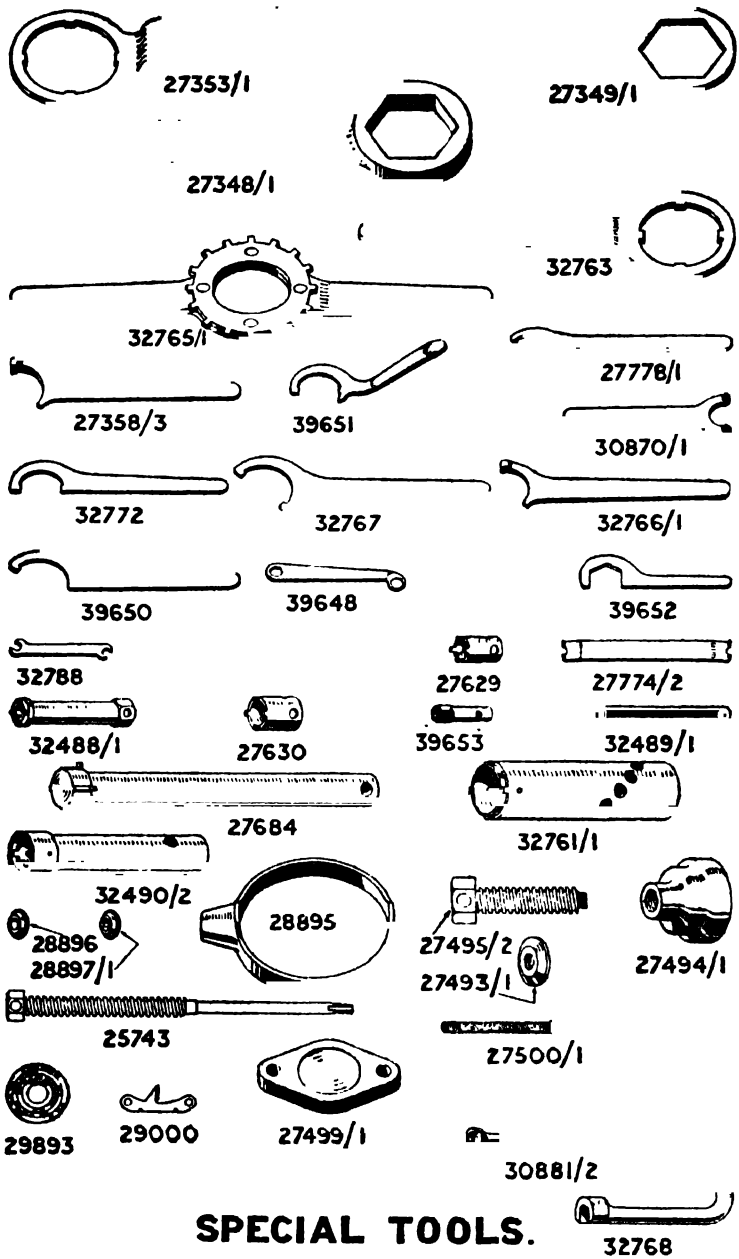


Fig. 848.—Illustration of Special Tools Used in Repairing Napier "Lion" Aero Engines.

Part No.	*Description*	*Quantity per set.*
	Box Spanners	
36820	Box Spanner 1/8″ × 3/16″ Whit. ..	1
36821	" " 1/4″ × 5/16″ " ..	1
36822	" " 3/8″ × 7/16″ " ..	1
36823	" " 1/2″ × 9/16″ " ..	1
36824	" " 5/8″ × 11/16″ " ..	1
	Jaw Spanners	
36812	Jaw Spanner 2BA × 1/4″ B.S.F. ..	1
36813	" " 1/4″ × 5/16″ " ..	1
36814	" " 5/16″ × 3/8″ " ..	1
36815	" " 3/8″ × 7/16″ " ..	1
36816	" " 7/16″ × 1/2″ " ..	1
36817	" " 9/16″ × 5/8″ " ..	1
36818	" " 11/16″ × 7/8″ " Thin Jaw	1
36819	" " 13/16″ × 15/16″ " " "	1
	Special Spanners and Tools	
27353	Spanner for Airscrew Boss Front Flange Nut	1
27683	End for Valve Seat Spanner......	1
27684	Valve Seat Spanner..................	1
27629	Spanner for Crank Front End Bolt	1
27630	Spanner for Crank. Front End Bolt Nut	1
27774	Pin Spanner for Valve Adjusting....	1
27778	Spanner for Valve Adjusting...	1
32765	Spanner for Airscrew Shaft Housing Front and Rear Nuts	1
32763	Spanner for Airscrew Front Bearing Nut	1
27358	Spanner for Camshaft Drive Bearing Cover....	1
26869	Tommy Bar, Large....	1
26880	Tommy Bar, Small............................	1
27775	Tommy Bar, 1/2″ dia	1
32488	Spanner for Diffuser Base.................	1
32489	Spanner for Main Jet and Gudgeon Pin Setscrew	1
32761	Spanner for Float Chamber Base Plug....	1
32490	Spanner for Diffuser Base Plug.................	1
27348	Spanner for Crankshaft Gear Wheel Nut, Crankshaft Rear Bearing Nut and Airscrew Boss Nut	
27349	Spanner for Airscrew Rear Bearing Nut.... ..	
30881	Special Spanner for Rear End Cover........	
30870	Spanner for Camshaft and Mag Bevel Nut	
32788	Carburetor Spanner (for Nuts 3/8″ across flats and 2 B.A.)	
32766	Spanner for Gland Nut.........................	
32767	Spanner for Camshaft Drive Tube End Piece....	
32768	Spanner for Cylinder Holding Down Nuts......	
32772	Spanner for Thrust Collar (Worm Shaft)......	
39650	"C" Spanner for 1¼″ Water Coupling..........	
39651	"C" Spanner for ¾″ Water Coupling...........	
39652	Flat Open Spanner for ¾″ Water Coupling.....	
39653	Box Spanner for Magneto Foot................	
39648	Flat Box Spanner for Magneto Foot and Induction Pipe Elbows	1
29000	Pointer for Crankshaft.........................	1
29893	Timing Plate	1
	Piston Position Indicator.....................	1
33697	Screwdriver (12″ long)	1

NAPIER-LION ENGINE TOOLS—Continued.

Part No.	Description	Quantity per set
33698	Screwdriver (6⅜" long)	1
	Hammer	1
	Pliers	1
	Tool Box	1
	Airscrew Boss Extractor	
27495	Bolt for Airscrew Boss Extractor	1
27493	Washer for Airscrew Boss Extractor	1
27494	Extractor for Airscrew Boss	1
	Gudgeon Pin Extractor	
28895	Gudgeon Pin Extractor	1
25743	Gudgeon Pin Extractor Screw	1
28896	Gudgeon Pin Extractor Collar	1
28897	Gudgeon Pin Extractor Washer	1
B.E.S.117G.	Nut	1
	Crankshaft Gear Extractor	
27499	Extractor for Crankshaft Gear Wheel	1
27500	Bolt for Crankshaft Gear Wheel	2
B.E.S.116H	Nut	2
	Magneto Spanners	
	Box Spanner for Cam Screw	1
	Spanner Set for Contact Breaker	1

Hispano-Suiza Tool Kit.—The tool outfit furnished with Hispano-Suiza twelve-cylinder Vee engines is shown at Fig. 849. The list follows:—16,474—Magneto breaker wrench. 16,473—Wrench for carburetor attaching plate. 16,475—Special wrench for propeller hub retention lock nut. 16,464—Special wrench for propeller hub retention nut. 15,844—End wrench for nuts holding cylinders. 16,463—Box wrench for camshaft retaing nuts. 15,577—Wrench for cylinder block bolts. 10,704—Special wrench for adjusting valve clearance. 16,476—Special wrench, double end, for removing air starter check valves. 16,477—Special box wrench. 10,706—Box wrench with crank handle to reach cylinder retention nuts. 16,467—Bar handle for wrenches number 16,470 and 16,463. 14,243—Bar handle for wrenches 16,476 and 16,473. 16,466—Bar handle for wrenches 14,489 and 16,469. 22,419 and 22,420—End wrenches. 15,842—Special end wrench for cylinder retention nuts. 16,468—Ratchet box wrench for connecting rod. 16,471—Spanner for ball bearing lock nut. 10,698—Spanner for vertical drive tube retention nuts. 16,465—Box wrench with crank handle for removing cylinder block cover. 22,421—End wrench. 15,584—Wrench for tightening carburetor float chamber retention nut. 16,469—Socket wrench for eight millimeter nuts. 14,489—Socket wrench for sparkplugs. 15,843—Special box wrench for cylinder retention nuts. 10,700—Gauge for valve clearance. 16,472—Wrench for magneto retention nut. 16,470—Long socket wrench.

Stands for Overhauling Airplane Engines.—After an airplane engine has been in use for a period ranging from 120 to 300 hours, depending upon the type, it is necessary to give it a thorough overhauling before it is returned to service. To do this properly, the engine is removed from the fuse-

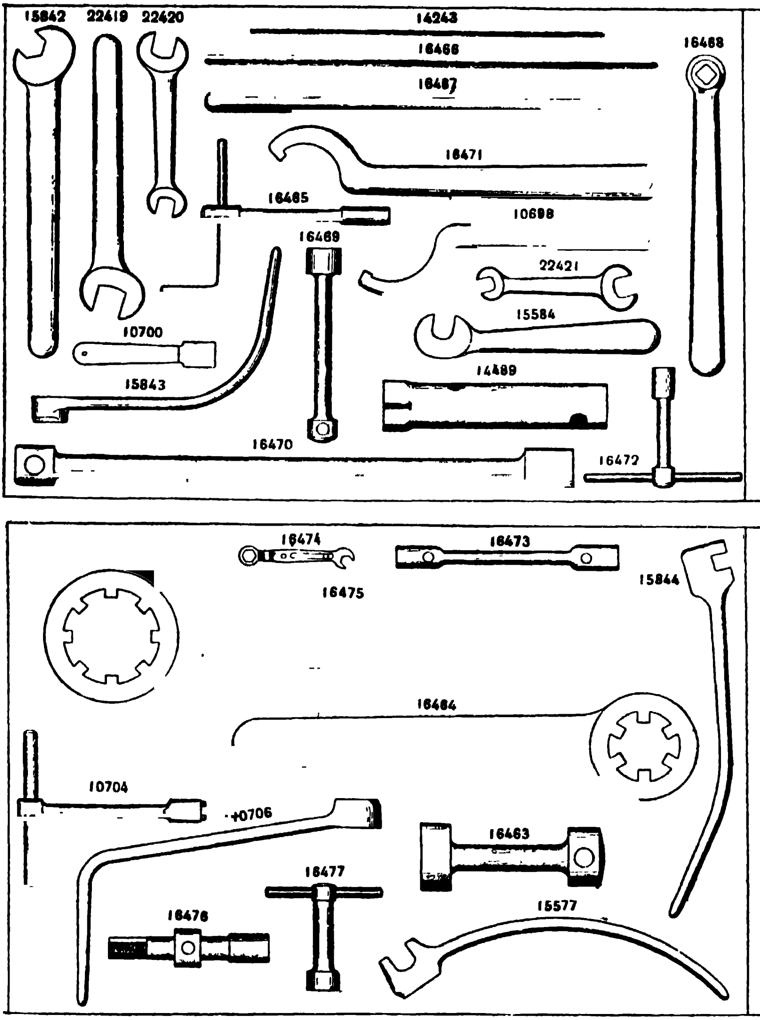


Fig. 849.—Special Tools Used in Dismantling and Repairing Hispano-Suiza Engines.

lage and placed on a special supporting stand, such as shown at Fig. 850, so it can be placed in any position and completely dismantled. With a stand of this kind it is as easy to work on the bottom of the engine as on the top and every part can be instantly reached. The OX2 motor crank-case shown in place in illustration is in a very convenient position for scraping in the crankshaft bearings. The entire assembly can be rolled around so any part can be reached and a clamp lock, not shown in the illustration, makes it possible to hold the stand in any desired position. Another type of engine stand, as recommended by the makers of Napier-Lion engines is shown at Fig. 851. This is well adapted for handling large

engines of the Vee or W form and the swinging cradle may be placed in various positions after the engine is in place. The stand is provided with small wheels so it can be moved about the shop. That shown at Fig. 850 is a fixed type because the supporting pedestals are bolted to the floor. Stands for radial engines are different in construction from those illustrated and blue prints of practical designs can be obtained from makers of such engines. The reader is referred to the chapters on repair and overhaul of specific types such as Siemens and Wright for suggestions.

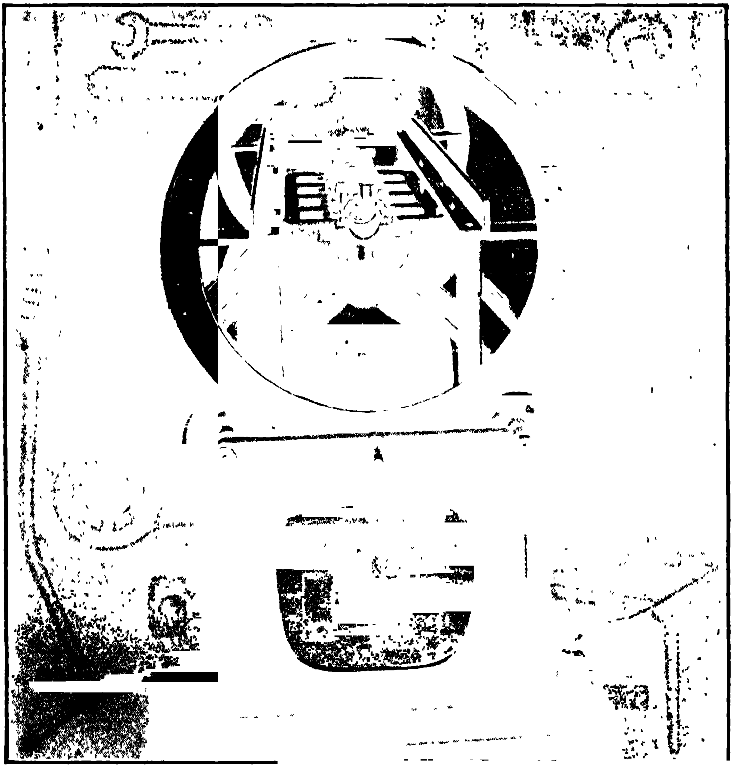


Fig. 850.—Special Stand to Make Motor Overhauling Work Easier. Stand Shown is Arranged for Curtiss OX Series Motors.

Stands for the propeller assembly and repair of various accessory groups should also be provided, and as the modern aviation engine is usually built up of a number of distinct assemblies, if some means are provided for working on these when they are removed from the powerplant, the repair work will be facilitated. All the shop specialists such as magneto and instrument men should have their own benches and test equipment. As an example of a simple bench stand for holding an engine part, the illustration at Fig. 852 is presented. This is self-explanatory and shows the swinging stand recommended by makers of the Napier-Lion engine for holding

the rear end crankcase assembly. As this includes the timing and accessory drive gears, water pump, etc., a convenient stand as shown greatly improves the work of checking or repairing the parts.

Numerous pieces of shop furniture can be made to store parts to prevent damage. For example, the long crankshafts of six-cylinder-in-line or Vee and W motors are easily distorted or sprung if carelessly handled. The

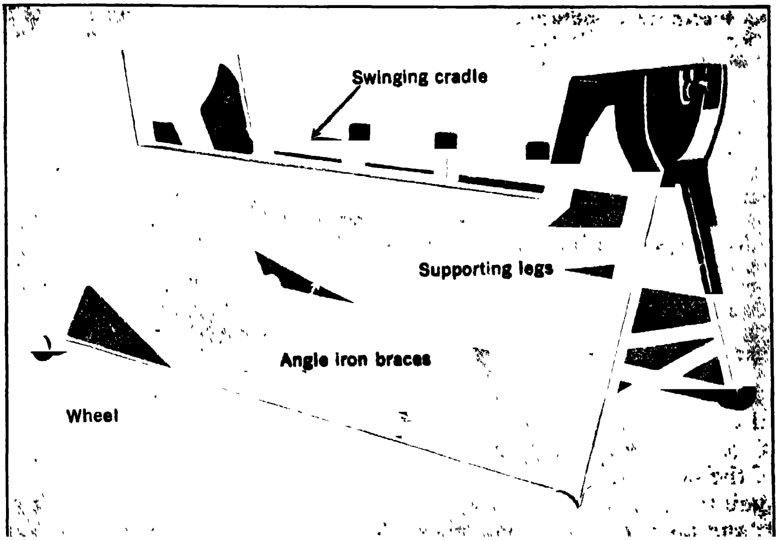


Fig. 851.—Special Stand Designed by Makers of Napier "Lion" Engines to Support Their Motors Can be Modified to Fit Any "Vee" or In-Line Motor.

supporting stand at Fig. 853 was used to store Curtiss OX crankshafts in the motor repair shops at Hazelhurst Field (now Curtiss Field) and as all dimensions are given and the construction is clearly shown, no difficulty should be experienced in either duplicating or modifying it. Special benches having bins and shelves to hold various parts are very valuable for use in connection with overhauling engines and can be devised to suit the particular type of engine worked on. For example, a rack can be built to hold each individual cylinder and the compartments may be further divided to hold the piston, connecting rod, etc., for each cylinder. Numbered holes in a bench top hold valves and prevent damage and a series of numbered pegs can be used for parts such as valve springs. All parts of an engine can thus be kept together and replacement will be positive and quickly accomplished when the engine is re-assembled.

QUESTIONS FOR REVIEW

1. Name some common hand tools useful in aero engine work.
2. Outline method of using micrometer caliper.
3. Name forms of hand drilling machines.
4. What are the best graduations on rules and scales?
5. Why are special engine stands valuable?

CHAPTER XLIV

GENERAL INSTRUCTIONS FOR OVERHAULING ENGINES

Marking Pieces for Identification—Usual Dismantling Procedure—Cleanliness of Parts Essential—Skilled Workmanship Imperative—Engine Reconditioning Operations —Defects in Cylinders—Carbon Deposits, Cause and Prevention—Use of Carbon Scrapers—Burning Out Carbon with Oxygen—Repairing Scored Cylinders—Sizing and Finishing Cylinders—Valve Removal and Inspection—Precautions in Reconditioning Valves—Reseating and Truing Valves—Valve Grinding Processes— Depreciation in Valve Operating Systems—Piston Troubles—Piston Ring Manipulation—Fitting Piston Rings—Wristpin Wear—Inspecting Crankshaft and Crankcase—Inspection and Refitting of Engine Bearings—Adjusting Main Bearings—Scraping Brasses to Fit—Remetaling Babbitt Bearings—Fitting Bearings by Boring—Assembling Roller Type Main Bearings to Crankshaft—Oil Retaining Plugs—Dismantling Roller Bearing Crankshaft—Fitting Connecting Rods— Sprung Camshaft—Precautions in Re-assembling Parts—Testing Bearing Parallelism—Final Inspection of Engine after Overhaul—Test after Overhaul—Running In—Two Hours Test—Half Hour Test—Maintenance of Engine in Stores— Selection of Tolerances and Running Fits, Napier-Lion Engine.

While specific instructions for repairing have been given in the various special chapters dealing with individual makes of engines, the reader will note that in these instructions the engine builders have made special mention of the precautions to be observed in overhauling their own engines and have pointed out the differences in mechanical construction between their design and more conventional types. While no general instructions can be given that will apply equally well to all types of aviation engines, there are certain mechanical processes that are the same in the main essentials in repairing all types. This chapter summarizes the instructions previously given and in some cases there may be a restatement of facts presented in other chapters, but these reviews are to make sure everything is fresh in the reader's mind. The various processes are considered more in detail in this chapter as in presenting the individual maker's engine instructions, the assumption was made that the reader was already familiar with repair shop practice to some extent. This chapter, read in connection with that preceding on tools used will serve as a good introduction to engine repair shop practice and should be of value to mechanics skilled in kindred lines, such as automobile repairing and in machine work.

Before working on any engine, the careful mechanic studies its construction and as no one can be expected to know everything, if something comes up he does not understand, he will find out about it, either from fellow workmen or by asking experts familiar with that particular engine. Some mechanics are ashamed to be seen consulting an instruction book and will blunder their way along when a few minutes study of a diagram would have made their work easier. Only the best grade of work is permissible on aviation engines and the slipshod methods of the average automobile repair garage cannot be tolerated on the flying field. Aviation mechanics must know what they are doing before they start. It is for that reason that the writer feels the following summary can be read to advantage by even

experienced mechanics. The beginner or student is not afraid to study and ask questions, it is the more expert who is apt to consider reference as to fits or tolerances, for example, of various engine parts to be beneath his dignity and in fitting pieces, he may use experience gathered with one engine when working on an entirely different type instead of finding out just what the engine builder recommends.

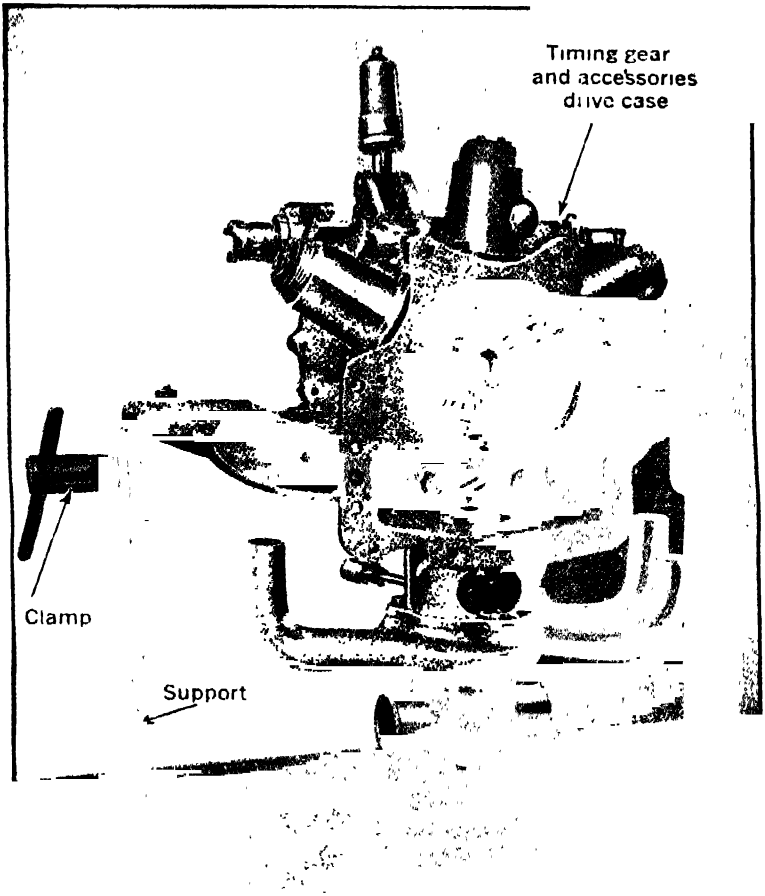


Fig. 852.—Special Swinging Stand for Accessories Drive Gears of Napier "Lion" Engines Useful to Illustrate Possibilities with Stands of this General Character for Other Assemblies.

Marking Pieces for Identification.—In order to look over the parts of an engine and to restore the worn or defective components after an extended period of flying it is necessary to take the engine entirely apart, as it is only when the powerplant is thoroughly dismantled that the parts can be inspected or measured to determine defects or wear. If one is not entirely

familiar with the engine to be inspected, even though the work is done by a repairman of experience, it will be found of value to take certain precautions when dismantling the engine in order to insure that all parts will be replaced in the same position they occupied before removal. There are a number of ways of identifying the parts, one of the simplest and surest being to mark them with steel numbers or letters if not already marked or with a series of center punch marks in order to retain the proper relation when re-assembling. This is of special importance in connection with dismantling multiple cylinder engines as it is vital that pistons, piston rings, connecting rods, valves, and other cylinder parts be always replaced in the same cylinder from which they were removed, because it is uncommon to find equal depreciation in all cylinders. Some repairmen use small paper shipping tags to identify the pieces. This can be criticised because the tags may become detached and lost and the identity of the piece mistaken. Metal tags with stamped numbers thereon and wired to the pieces to be identified are not so apt to be lost as cardboard or paper tags attached with string are. If the repairing is being done in a shop where other engines of the same make are being worked on, the repairman should be provided with a large chest fitted with a lock and key in which all of the smaller parts, such as rods, bolts and nuts, valves, gears, valve springs, camshafts, etc., may be stored to prevent the possibility of confusion with similar members of other engines. All parts should be thoroughly cleaned with gasoline or in the potash kettle as removed, and wiped clean and dry. This is necessary to show wear which will be evidenced by easily identified indications in cases where the machine has been used for a time, but in others, the deterioration can only be detected by delicate measuring instruments.

Usual Dismantling Procedure.—In taking down a motor the smaller parts and fittings such as sparkplugs, manifolds and wiring should be removed first. Then the more important members such as cylinders may be removed from the crankcase to give access to the interior and make possible the examination of the pistons, rings and connecting rods. After the cylinders are removed the next operation is to disconnect the connecting rods from the crankshaft and to remove them and the pistons attached as a unit. Then the crankcase is dismembered, in most cases by removing the bottom half or oil sump, thus exposing the main bearings and crankshaft. The first operation is the removal of the inlet and exhaust manifolds. In order to remove the carburetor it is necessary to shut off the gasoline supply at the tank and to remove the pipe coupling at the float chamber. It is also necessary to disconnect the throttle operating rod. After the cylinders are removed and before taking the crankcase apart it is well to remove the water pump and magneto. The wiring on most engines of modern development is carried in conduits and usually releasing two or three minor fastenings will permit one to take off the plug wiring as a unit. The wire should be disconnected from both sparkplugs and magneto distributor before its removal. When the cylinders are removed, the pistons, piston rings, and connecting rods are clearly exposed and their condition may be readily noticed.

Before disturbing the arrangement of the timing gears, it is important that these be marked so that they will be replaced in exactly the same relation as intended by the engine designer. If the gears are properly marked

the valve timing and magneto setting will be undisturbed when the parts are replaced after overhauling. With the cylinders off, it is possible to ascertain if there is any undue wear present in the connecting rod bearings at either the wristpin or crankpin ends and also to form some idea of the amount of carbon deposits on the piston top and back of the piston rings. Any wear of the timing gears can also be determined. The removal of the bottom plate of the engine enables the repairman to see if the main bearings are worn unduly. Often bearings may be taken up sufficiently to eliminate all looseness. In other cases they may be worn enough so that

Fig. 853.—Simple Rack Made of Lumber to Hold Curtiss OX Series Crankshafts and Prevent Damaging Them Due to Careless Storage.

careful refitting will be necessary. Where the crankcase is divided horizontally into two portions, the upper one serving as an engine base to which the cylinders and in fact all important working parts are attached, the lower portion performs the functions of an oil container and cover for the internal mechanism. This is the construction generally followed.

Cleanliness of Parts Essential.—Since the presence of dirt, grime and grease furnish little inspiration for painstaking and accurate workmanship but, on the contrary, greatly decrease the efficiency of even the best mechanics, the first operation should be a thorough washing of the engine by its complete submersion in a tank of hot water and washing soda, or any one of the several excellent washing solutions marketed under well-known trade names. The engine should then be mounted on a universal engine-stand and completely dismantled. Then the separate parts should be washed again to remove all traces of grease and oil. At the same time, all oil lines in the crankcase and crankshaft should be blown out and thoroughly cleaned. A careful inspection and check-up should then be made of all parts that are subject to warpage or wear. Only by such a procedure can the conditions requiring correction be determined, and this inspection work should always be done by a capable mechanic, skilled in the use of micrometers and other precision instruments It is assumed, of course, that every shop attempting the reconditioning of automotive engines is equipped with a full set of precision measuring instruments, such as inside and outside micrometers, surface plates, dial gauges and test indicators.

Skilled Workmanship Imperative.— It is almost criminal for anyone who lacks a knowledge of elementary mechanical engineering principles and micrometer experience to take down and attempt to re-assemble a machine built with such exactness as an aviation engine. Successful reconditioning of such an engine depends upon the utmost exactness in aligning or squaring each part with all the others, starting with the cylinder base-line of the crankcase as datum and securing perfect parallelism with that base of the crankshaft and the camshaft, the main bearings, connecting-rod bearings, piston-pins and camshaft bearings, and squaring the cylinder bores and the connecting rods at perfect right angles to the base line. An error at one point cannot be compensated for at another point. Refinishing worn cylinders, fitting new pistons, line-boring and fitting bearings and bushings, grinding and realigning crankshafts and similar work call for operations and tolerances measurable in thousandths and even in ten-thousandths of an inch This necessitates the employment of special precision instruments and special machine-tools and a knowledge of their proper use.

Engine Reconditioning Operations.—The major operations of reconditioning an engine, following the preliminary washing and complete taking down of the engine and the examination and checking of the parts with micrometers, surface plates, dial gauges and test indicators, are described in a paper published in the *S. A. E. Journal* by Robert C. McWane and various excerpts are reproduced in this chapter. Methods of refinishing cylinders, as boring, reaming, honing and grinding, are described and attention is directed to the difference in application of these methods in the factory and in the reconditioning shop. Use of a heavy-duty cylinder-grinding machine is recommended as the only method that is capable of restoring the

original trueness of the cylinder bore with the base of the cylinder-block and satisfactorily and economically correcting worn and warped cylinders with the minimum loss of metal and of producing a finished surface equal or superior to that produced by any other method, according to Mr Mc-Wane.

The importance of keeping the crankshaft in perfect condition is emphasized, but the reconditioning of a shaft that is worn or out of alignment should never be attempted by filing, turning, lapping or polishing Crankshaft grinding requires extreme care and satisfactory results can be obtained only by the use of machines built especially for the purpose. The most exacting part of a reconditioning job is the fitting of the main and connecting-rod bearings, and the best engineering practice calls for the use of a type of universal equipment having a cutter-tool bar that can be adjusted with micrometer accuracy. When a crankshaft has been reground, new undersize main bearings should be used, as otherwise the timing-gear centers will be changed and the pitch line of the gear train disturbed, causing the gears to jam and become noisy.

The difference between fitting bearings into a new crankcase and into an old one is great. To compensate for wear and warpage in an old one, the bearing halves should be left from 0.002 to 0.003 inch above the crankcase and cap faces, so that when bolting the cap on the case the bearings will have a drive fit. Other operations in fitting and boring the bearings are explained in proper sequence. The fitting of timing-gears, camshafts, idler gears and their bushings and water-pump and magneto shafts and the putting into mechanical order of the valve push-rods and adjusting screws require as great precision as the major operations.

Defects in Cylinders.—After the cylinders have been removed and stripped of all fittings, they should be thoroughly cleaned and then carefully examined for defects. The interior or bore should be looked at with a view of finding score marks, grooves, cuts or scratches in the interior, because there are many faults that may be ascribed to depreciation at this point. The cylinder bore may be worn out of round, which can only be determined by measuring with an internal caliper or special dial indicator fixture even if the cylinder bore shows no sign of wear. The flange at the bottom of the cylinder by which it is held to the engine base may be warped or cracked. The water jacket may have opened up due to freezing of the jacket water at some time or other or it may be filled with scale and sediment due to the use of impure cooling water. Aviation engine cylinders using steel water jackets should be carefully tested to make sure the jacket has not corroded. The valve seat may be scored or pitted. The detachable head construction makes it possible to remove that member and obtain ready access to the piston tops for scraping out carbon without taking the main cylinder portion from the crankcase but this method of construction is not found on many aviation engines. When the valves need grinding a detachable head may be removed and carried to the bench where the work may be performed with absolute assurance that none of the valve grinding compound will penetrate into the interior of the cylinder as is sometimes unavoidable with the I-head cylinder having head integral. If the cylinder should be scored, the water jacket and combustion head may be saved and a new cylinder casting purchased

at considerably less cost than that of the complete unit cylinder.

The detachable head construction has only recently been applied on airplane engines, though it was one of the earliest forms of automobile engine construction. In the early days it was difficult to procure gaskets or packings that would be both gas and water tight. The sheet asbestos commonly used on early engines was too soft and blew out readily. Besides a new gasket had to be made every time the cylinder head was removed. Woven wire and asbestos packings impregnated with rubber, red lead, graphite and other filling materials were more satisfactory than the soft sheet asbestos, but were prone to burn out if the water supply became low. Materials such as sheet copper or brass proved to be too hard to form a sufficiently yielding packing medium that would allow for the inevitable slight inaccuracies in machining the cylinder head and cylinder. The invention of the copper-asbestos gasket, which is composed of two sheets of very thin, soft copper bound together by a thin edging of the same material and having a piece of sheet asbestos interposed solved this problem. Copper-asbestos packings form an effective seal against leakage of water and a positive retention means for keeping the explosion pressure in the cylinder. The great advantage of the detachable head is that it permits of very easy inspection of the piston tops and combustion-chamber and ready removal of carbon deposits. In air-cooled engines, however, the cylinder heads are usually integrally cast or permanently assembled thereto because superior cooling is obtained by that method of construction.

Carbon Deposits, Their Cause and Prevention.—Most authorities agree that carbon is the result of imperfect combustion of the fuel and air mixture as well as the use of lubricating oils of improper flash point. Lubricating oils that work by the piston rings may become decomposed by the great heat in the combustion-chamber, but at the same time one cannot blame the lubricating oil for all of the carbon deposits. There is little reason to suspect that pure petroleum oil of proper body will deposit excessive amounts of carbon, though if the oil is mixed with castor oil, which is of vegetable origin, there would be much carbon left in the interior of the combustion-chamber. Fuel mixtures that are too rich in gasoline also produce these undesirable accumulations.

A very interesting chemical analysis of a sample of carbon scraped from the interior of a motor vehicle engine shows that ordinarily the lubricant is not as much to blame as is commonly supposed. The analysis which undoubtedly differs considerably from that of carbon from an aviation engine was as follows:

Oil	14.3%
Other combustible matter	17.9
Sand, clay, etc	24.8
Iron oxide	24.5
Carbonate of lime	8.9
Other constituents	9.6

It is extremely probable that the above could be divided into two general classes, these being approximately 32.2 per cent oil and combustible matter and a much larger proportion, or 67.8 per cent of earthy matter. The presence of such a large percentage of earthy matter is undoubtedly due to the impurities in the air, such as road dust which has been sucked in

through the carburetor. The fact that over seventeen per cent of the matter which is combustible was not of an oily nature lends strong support to this view. There would not be the amount of earthy material present in the carbon deposits of an airplane engine as above stated because the air is almost free from dust at the high altitudes planes are usually flown. One could expect to find more combustible and less earthy matter and the carbon would be softer and more easily removed It is very good practice to provide a screen on the air intake to reduce the amounts of dust sucked in with the air as well as observing the proper precautions relative to supplying the proper quantities of air to the mixture and of not using any more oil than is needed to insure proper lubrication of the internal mechanism. The important points to keep in mind if airplane engine carbon deposits are to be kept at a minimum are the use of proper lubricant and fuel, though training airplanes which make frequent landings and take-offs and fly nearer the ground than service planes do could use air filters advantageously, as could planes used for "passenger hops."

Use of Carbon Scrapers.—It is not unusual for one to hear an aviator complain that the engine he operates is not as responsive as it was when new after he has run it but relatively few hours. There does not seem to be anything actually wrong with the engine, yet it does not respond readily to the throttle and is apt to overheat While these symptoms ordinarily denote a rundown and worn condition of the mechanism, the trouble is often due to nothing more serious than accumulations of carbon and need of valve grinding. The remedy is the removal of this matter out of place. The surest way of cleaning the inside of the motor thoroughly is to remove the cylinders, if these members are cast integrally with the head or of removing the head member if that is a separate casting, to expose all parts.

In certain forms of cylinders, it is possible to introduce simple scrapers through the sparkplug hole if this component is placed in the cylinder in some position that communicates directly to the interior of the cylinder or to the piston top No claim can be made for originality or novelty of this process as it has been used for many years on large stationary engines. The first step is to dismantle the inlet and exhaust piping and remove the sparkplugs, although if the deposit is not extremely hard or present in large quantities one can often manipulate the scrapers in the openings without removing either the piping or the valves. Carbon can be removed from the valve port interiors through the large openings left by the removal of the piping. Commencing with the first cylinder, the crankshaft is turned till the piston is at the top of its stroke, then the scraper may be inserted, and the operation of removing the carbon started by drawing the tool toward the opening. As this tool is similar to a small hoe, the cutting edge will loosen some of the carbon and will draw it toward the opening. A swab is made of a piece of cloth or waste fastened at the end of a wire and well soaked in kerosene to clean out the cylinder.

When available, an electric motor with a length of flexible shaft and a small circular cleaning brush having wire bristles can sometimes be used in the interior of the engine. The electric motor need not be over one-eighth horsepower running 1,200 to 1,600 r.p.m., and the wire brush must, of course, be of such size that it can be easily inserted through the sparkplug holes. The flexible shaft permits one to reach nearly all parts of the

cylinder interior without difficulty and the spreading out and flattening of the brush insures that considerable surface will be covered by that member. Most airplane engines are so constructed that a thoroughly good job of carbon removal can be accomplished only by removing the cylinders to expose the cylinder combustion-chamber interiors and the piston tops. This permits of thorough removal of all foreign matter and no ridges of carbon are left as is the case when scrapers are introduced through spark-plug holes.

Burning Out Carbon with Oxygen.—A process that gives very good results in removing carbon without disassembling the motor depends on burning out that material by supplying oxygen to support the combustion and to make it energetic. A number of concerns are already offering apparatus to accomplish this work, and in fact any shop using an autogenous welding outfit may use the oxygen tank and reducing valve in connection with a simple

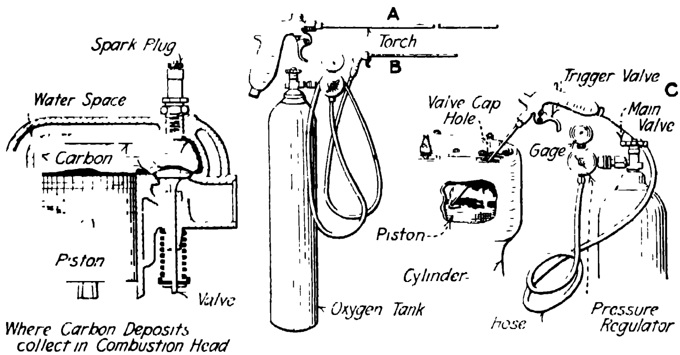


Fig. 854.—Showing Where Carbon Deposits Collect in Combustion-Chamber and How to Burn Them Out with Oxygen. A—Special Torch Used. B—Torch Coupled to Oxygen Tank Reducing Valve. C—Torch in Use.

special torch for burning the carbon. Results obtained with automobile engines have demonstrated that there is little danger of damaging the motor parts though the heat generated might distort the lighter aviation engine pieces and that the cost of oxygen and labor is much lower than the old method of removing the cylinders and scraping the carbon out, as well as being very much quicker and more positive than the alternative process of using carbon solvent. The only drawback to this system is that there is no absolute insurance that every particle of carbon will be removed, as small protruding particles may be left at points that the flame does not reach and cause preignition and consequent pounding, even after the oxygen treatment. It is generally known that carbon will burn briskly in the presence of oxygen, which supports combustion of all materials, and this process takes advantage of this fact and causes the gas to be injected into the combustion-chamber over a flame initially obtained by a match or wax taper.

It is suggested by those favoring this process that the night before the oxygen is to be used the engine be given a simple kerosene treatment. A

half tumbler full of this liquid or of denatured alcohol is to be poured into each cylinder and permitted to remain there over night. As a precaution against fire, the gasoline is shut off from the carburetor before the torch is inserted in the cylinder and the motor started so that the gasoline in the pipe and carburetor float chamber will be consumed Work is done on one cylinder at a time being sure that both valves are closed and the piston is at the top of its compression stroke A note of caution was recently sounded by a prominent sparkplug manufacturer recommending that the plug be removed from the cylinder in order not to injure it by the heat developed. The outfits on the market consist of a special torch having a trigger controlled valve and a length of flexible tubing such as shown at Fig. 854 A, and a regulating valve and oxygen tank as shown at B The gauge should be made to register about twelve pounds pressure. The method of operation is very simple and is outlined at C. The burner tube is placed in the cylinder and the trigger valve is opened and the oxygen permitted to circulate in the combustion-chamber. A lighted match or wax taper is dropped in the chamber and the injector tube is moved around as much as possible so as to cover a large area. The carbon takes fire and burns briskly in the presence of the oxygen The combustion of the carbon is accompanied by sparks and sometimes by flame if the deposit is of an oily nature. Once the carbon begins to burn the combustion continues without interruption as long as the oxygen flows into the cylinder. Full instructions accompany each outfit and the amount of pressure for which the regulator should be set depends upon the design of the torch and the amount of oxygen contained in the storage tank. This method should be used only if it is sanctioned by the engine builder because aviation engine construction is different in many important respects from automobile engines which have been cleared of carbon successfully by this method.

Repairing Scored Cylinders.—If the engine has been run at any time without adequate lubrication, one or more of the cylinders may be found to have vertical scratches running up and down the cylinder walls. The depth of these will vary according to the amount of time the cylinder was without lubrication, and if the grooves are very deep the only remedy is to purchase a new member. Of course, if sufficient stock is available in the cylinder walls, the cylinders may be rebored and new pistons which are oversize, *i.e.*, larger than standard, may be fitted. As a rule, aviation engine cylinders are so thin that reboring or regrinding operations are not practical if the scratches are very deep. Where the scratches are not deep they may be ground out with a high speed emery wheel cylinder grinder or lapped out if that type of machine is not available. Wristpins have been known to come loose, especially when these are retained by set screws that have not been properly locked, and as wristpins are usually of hardened steel it will be evident that the sharp edge of that member can act as a cutting tool and make a pronounced groove in the cylinder. Cylinder grinding is a job that requires skilled mechanics, but it may be accomplished on any large lathe fitted with an internal grinding attachment though special cylinder grinders equipped with substantial and heavy fixtures to hold the cylinders do the best work. While automobile engine cylinders usually have sufficient wall thickness to stand reboring, those of airplane engines seldom have sufficient metal to permit of enlarging the

bore very much by a boring tool. A few thousandths of an inch may be ground out without danger, however. An airplane engine cylinder with deep grooves must be scrapped as a rule.

Where the grooves in the cylinder are not deep or where it has warped enough so the rings do not bear equally at all parts of the cylinder bore, it is possible to obtain a fairly accurate degree of finish by a lapping process in which an old piston or a special expanding lead lap is coated with a mixture of fine emery and oil and is reciprocated up and down in the cylinder as well as turned at the same time. This may be easily done by using a dummy connecting rod having only a wristpin end boss, and of such size at the other end so that it can be held in the chuck of a drill press. The cylinder casting is firmly clamped on the drill press table by suitable clamping blocks, and a wooden block is placed in the combustion-chamber to provide a stop for the piston at its lower extreme position The back gears are put in and the drill chuck is revolved slowly All the while that the piston is turning the drill chuck should be raised up and down by the hand feed lever, as the best results are obtained when the lapping member is given a combination of rotary and reciprocating motion. A process of recent development makes it possible to repair deep scores in cylinders by electro-deposition and another process involves filling the groove with silver solder but either of these methods are advisable only if it will be difficult to secure a new replacement member.

Sizing and Finishing Cylinders.—Boring was the original and, for some time the only, method of finishing engine cylinders, but it was long ago recognized that friction is the highway robber of mechanical energy. Since an early period in the history of the gas engine, when it was necessary to run a new engine with a belt for several days to limber it up sufficiently to keep it moving from one explosion to another with the help of a heavy flywheel, engineers have been seeking a solution of the problem in the development of machines for finishing cylinders more perfectly. Boring machines have been improved greatly in recent years, especially the heavy-duty type for production work, but it is the lack of uniformity in cast iron, of which automobile and some aerial engine cylinders are made, that renders it impossible for a boring tool to produce a finish without high and low spots still existing. The steel sleeves comprising composite aviation engine cylinders are more uniform in structure and boring and turning operations are necessary before the final finish by grinding or lapping. Cast iron or semi-steel air-cooled engine cylinders are roughed out by a boring operation.

Reaming is but a modification of the boring method, and, while claims are made of better results in finish than by boring, the increased pressure on the cylinder walls by reason of the greater area of cutting members, causes the thin portions of the wall to spring away from the cutters, and when the reamer is withdrawn these thin portions spring back, leaving low places at the reinforced parts of the wall. In the resizing of worn engine cylinders it is desirable to remove the least possible amount of metal requisite to restore the bore to a round, true, straight and smooth condition. Even if all other requirements could be met successfully with boring or reaming tools, they would have to be set to remove an abnormal amount of

metal as compared with other methods, owing to the glazed surface of the cylinder wall preventing the cutters from taking hold.

Honing is a cylinder-finishing process that has come into extensive use recently. The machine, or tool, consists of a metal frame or cradle supporting three to six abrasive stones that are pressed against the cylinder walls by springs. The hand-operated type is usually revolved in the cylinder by a portable electric drilling machine, being moved up and down at the

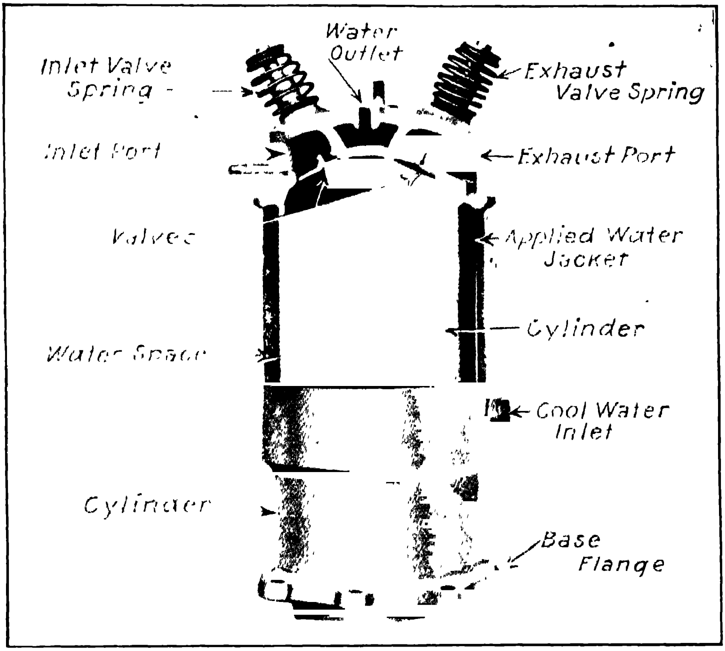


Fig. 855.—Part Sectional View, Showing Valve Arrangement in Cylinder of Curtiss OX2 Aviation Engine.

same time, somewhat after the manner of the cylinder lap. The power hone is operated by a drill press or a special honing machine is used. A survey of the cylinder-finishing methods employed by 24 well-known builders of automobiles and engines, made early in 1924 by the Research Department of the S A E., disclosed that twelve of the number honed the cylinders, nine finish-ground them and the remaining three used the lapping process. In no case was the hone used as a sizing and corrective operation except as a means for removing the tool marks and high spots that remain after reaming, or the slight roughness left after production grinding, and to give a highly-polished surface Grinding is the best method of reconditioning cylinder bores in the opinion of the majority of authorities consulted by the writer but the work should be done only by skilled mechanics and on cylinder grinders specially made for the purpose equipped with fixtures heavy enough to keep the cylinder from springing. Even if grinding is used to remove metal, the honing process often follows it to give a smooth bore.

Valve Removal and Inspection.—One of the most important parts of the gasoline engine and one that requires frequent inspection and refitting to keep in condition, is the mushroom or poppet valve that controls the inlet and exhaust gas flow. In overhauling it is essential that these valves be removed from their seatings and examined carefully for various defects which will be enumerated at proper time. The problem that concerns us now is the best method of removing the valve. These are held against the seating in the cylinder by a coil spring which exerts its pressure on the cylinder casting at the upper end and against a suitable collar held by a key at the lower end of the valve stem. In order to remove the valve it is necessary to first compress the spring by raising the collar and pulling the retaining key out of the valve stem. Many forms of valve spring lifters have been designed to permit ready removal of the valves.

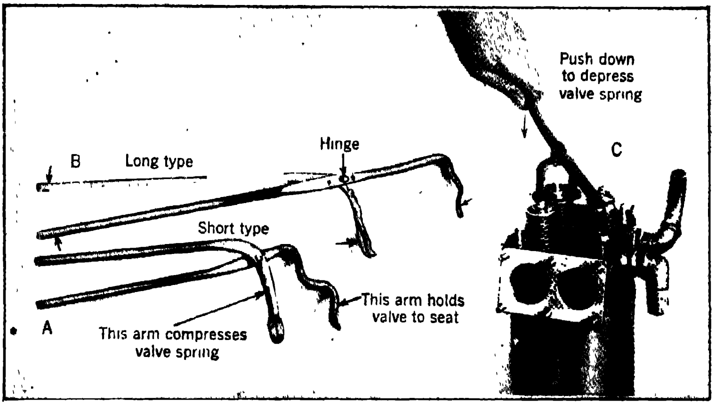


Fig. 856.—Valve Spring Compression Tongs at A and B. Special Valve Spring Compressor Used with Fiat Engine Cylinder Shown at C.

When the cylinder is of the valve-in-the-head form, the method of valve removal will depend entirely upon the system of cylinder construction followed. In some early cylinder designs it was possible to remove the head from the cylinder castings and the valve springs may be easily compressed by any suitable means when the cylinder head is placed on the work bench where it can be easily worked on. The usual method is to place the head on a soft cloth with the valves bearing against the bench. The valve springs may then be easily pushed down with a simple forked lever and the valve stem key removed to release the valve spring collar. In the Curtiss OX engines having a cylinder as shown at Fig. 855, and all other engines using one piece cylinders it is not possible to remove the valves without taking the cylinder off the crankcase, because the valve seats are machined directly in the cylinder head and the valve domes are cast integrally with the cylinder. This means that if the valves need grinding the cylinder must be removed from the engine base to provide access to the valve heads which are inside of that member, and which cannot be reached from the outside as is true of the L-cylinder construction. In the Curtiss VX engines, the valves were carried in detachable cages which could be removed when the valves need attention but this

construction is now obsolete and most modern engines have cylinders with heads integral. In cases where sparkplug holes are placed adjacent a valve so the valve head may be kept from moving, the tong type of valve spring compressor may be used. The longer handle or member has a piece bent at right angles that is introduced through the sparkplug hole and keeps the valve pressed against the seat while the other part bears against the valve spring retaining collar. Squeezing the tong handles together depresses the spring and the collar retention pin, key or split cone may be released from the valve stem. These may be made in various types as shown at Fig. 856 A and B. This type has been used successfully where the cylinder construction permitted. A valve spring compressor used with the Fiat four valve cylinders is shown at Fig. 856 C. A rod is introduced through the sparkplug hole to hold the valve head against the seat while the valve spring retaining collar is pressed down and the spring compressed sufficiently to permit removal of the collar retention members. The lever carries a hook at one end which engages a nut screwed on one of the valve gear case retention studs while a swinging member between the hook and that portion of the handle where pressure is applied has a pad to bear against the spring collar as indicated. As four studs are used on each cylinder, all the valves may be depressed in turn by shifting the anchorage hook from one stud to the other depending on which valve is to be removed. Other valve spring removers have been shown in the chapters relating to overhaul of specific types of engines, so the mechanic should not be at a loss for suggestions to make valve spring compressors to fit almost any type of engine.

Precautions in Reconditioning Valves.—In a paper read before the New England Section of the S. A. E., Jack Frost, field engineer of the Willis-Jones Machine Co., Detroit, Mich., discussed reconditioning of engine valves in a very interesting manner. He stated that perfect valve action is complete, quiet closing at any speed. To show what is necessary some simple sketches that cover the principal causes of 90 per cent of the valve troubles that have been encountered ever since the advent of the automotive engine are shown at Fig. 857. At the left a valve-seat in perfect alignment with the center line of a perfect valve-stem guide is shown. The left-center drawing shows a perfect valve having the face concentric with the center line of the stem. At the right-center is drawn a valve with the head and face warped from the correct angle with the center line of the stem. Assuming that the guide measures 0.375 inch in diameter and these two stems measure 0.374 inch each, the guide clearance is 0.001 inch. This is as close a fit as will allow a valve to drop of its own weight in a hole or guide of this size. The valve at the right-center in Fig. 1 would not seat itself. The low side would strike and the valve would be held open on the opposite side. The valve at the left-center will seat perfectly, as its face will touch the entire circumference of the seat, and the valve does not require more than its own weight to seat itself. For the valve at the righ-center to seat, it is necessary that the clearance between the stem and the guide be sufficient to permit the stem to assume an angle in the guide corresponding to the misalignment between the valve face and the valve-stem, as indicated at the extreme right in Fig. 857 D.

Whether the clearance is 0.0015 or 0.0100 inch, the stem must have enough clearance in the guide to close through any eccentricity present.

The spring pulls the stem sharply against the wall of the guide with a sharp metallic click, unless the clearance is excessive. The valve-spring on all automobiles is designed with just enough tension for closing the valve at top speed of the camshaft. It will travel or extend at only one given speed, according to its tension, but the camshaft has a variable speed. In most cases when an engine is taken down, it is found that only one or two valves are burned. If the metal in the valve were at fault, all the valves would burn under the same speed or heat conditions. When a valve does not close completely, the compressed burning gas, which reaches, under ordinary operating conditions, a temperature of 1,500 to 2,500 degrees Fahrenheit, is forced with great velocity through the small opening left and burns the valve face or warps the stem. Were it possible to cut the valve-seat in perfect alignment with the guide and to cut the valve face true with the stem, we should not require more than 0.0015-inch clearance between the stem and the guide.

Assume that the valve-seat and the valve-stem guide are perfectly true with each other and that the valve face is true with its stem when the engine is assembled at the factory; still the seats and guides are subject to seasoning, as is the case with all parts made of cast iron, and the intense heat generated in the automotive engine brings a rapid change in the texture of the metal and distorts these parts For this reason tungsten steel or case hardened steel guides are often used in aviation engines though cast iron is the metal generally employed in automobile motors. Phosphor bronze guides have also been used in alloy heads because its expansion coefficient is nearer that of alloy than steel or iron guides.

In the seasoning of cast iron, the metal becomes irregular in density and hardness, sometimes producing spots or portions that are many times harder than the surrounding metal Should one or more of these hard spots appear in or near the surface of the valve-seat, the hammer-like blows of the valve will tend to produce faster wear in the softer metal at the opposite side of the seat. Although the seasoning and resultant warping of cast iron starts with the cooling of the casting in the foundry, this action continues indefinitely but diminishes slowly with age or use. The valve-stem guides sometimes require from 1,000 to 2,000 miles of running before they have become permanently set or seasoned. Thus, every hour's operation of the engine adds to the value of the material in these parts, but makes it necessary to service or recondition the valve-seats as soon as possible after the engine shows such reconditioning to be needed

The guide, a small member held by less than 50 per cent of its own length and extending, as it does, into the valve port where the heat from the burning gas has greater opportunity to warp it, sometimes loses its perfect alignment with the seat and changes the direction of travel of the valve. The spring has the power to close the valve regardless of this untrue condition, but does so through a second unnecessary movement, the valve striking a small portion of the seat first and then gaining the full seat through a pendulum-like swing of the stem. This produces a metallic click that defies removal through reducing the tappet clearance.

If one must cut a seat in metal that contains different degrees of hardness, the cut will show slight chatter marks if examined closely. It is impossible to prevent these chatter marks. When the cutter reaches the hard

spots, regardless of the weight of the tool, it will first slow down and then speed up as it gets through the hard spots, pulling the softer metal beyond or forcing the cutter away. If, after cutting the seat as perfectly as possible, an attempt is made to grind it, the grinding compound is resisted by the hard spot and the seat is ground into further misalignment because of the softer metal opposite taking the grinding far faster than the hard spot.

It is sometimes said that it is foolish to cut away the scale when recutting the valve-seat, as it has been a long time in arriving at the condition of a glazed, hard surface. However, if cutting is done with compound and with the valve only, the scale is being cut and it is not known whether the alignment is being corrected. If the seat is being cut before grinding, all scale must be removed from the full surface; otherwise a hard, glazed spot may be left that will resist the pounding of the valve while permitting the soft metal on the opposite side to be pounded into misalignment.

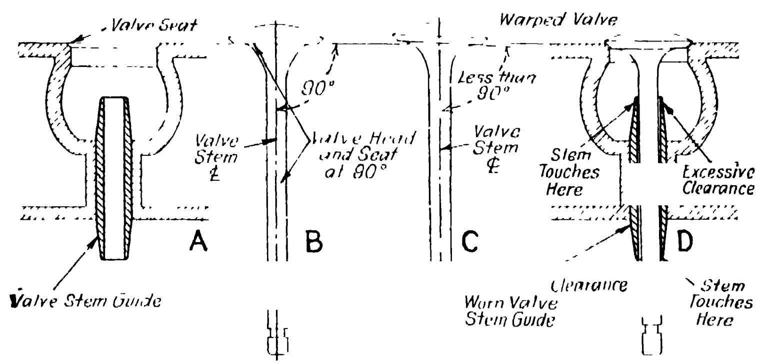


Fig. 857.—Valve Seat and Guide Relation Shown at A. B Shows Valve Head and Stem in Proper Relation. C Outlines Warped Valve Head. D Shows How Excessive Clearance is Needed in Valve Stem Guide to Allow Misaligned Valve to Seat Itself Completely.

Much difference of opinion exists as to the proper width of the valve-seat face. Some engines have a seat width of 1/64 inch and some have about 5/32 inch. The best width of seat for average work is about 3/32 inch. The seat should not be less than 3/32 inch on the smaller valves. In recutting the valve-seat, all scale and glaze is removed and the surface is left furred or soft. If the seat is too narrow, the hammer-like blows of the valve will easily pound this down, constantly changing the tappet clearance. Another condition to be avoided, especially if bronze inserts are used in alloy heads is the use of narrow seats which might reduce heat transfer from head to seating.

Upon removing valves for grinding, and after cleaning carbon from the valve and stem and checking the stem for wear, it should be remembered that, if the guide shows 0.002-inch wear, a new valve-stem would have a possible 0.006 or 0.007-inch clearance. To prevent possible leakage of the exhaust and imperfect carburetion, the valve-stem should not show wear in excess of 0.003 inch. It is not the amount of wear on either the stem or the guide that gives trouble, but the excessive clearance that would result in

wear showing in both units; therefore, through the aid of plus pilots, we must check the guide size and replace the valves if the old stem shows that clearance will be greater than 0.008 inch, or must rebore the guide or use new guides if of hardened steel and use new valves with oversize stems.

It should also be remembered, when chucking or holding the valve-stem for refacing in a valve facing machine or in a lathe that the wear on the stem is not evenly distributed. When attempting to reface a valve showing excessive wear on one side of the stem, be sure to hold the valve-stem by the unworn section just above the point of wear. If the refaced valve is very thin at the outer edge, the valve should be replaced, as the thin edge will burn. It is a good plan to test the setting of the work-head of the valve-refacing machine with a new valve and, after locking the head on a 45-degree angle, to grind or sharpen the 45-degree seat-cutters so that seats and valves will have the same angle and mate perfectly. Of course, if the valve head has a 30 degree angle the proper head adjustment must be made.

Do not, under any circumstances, lap the valve to the seat heavily, as it is possible to ruin a seat and never secure a true result from the work. Only light lapping is ever necessary if the seat and the guide are true with each other and the valve face is true with the stem, and then only to remove slight chatter marks. Should any blank spots appear on the valve, this would show faulty refacing and the valve-refacing machine should be corrected. Should blank spots appear on the seat, the tool should be set up and checked with a new cut with a cutter, making sure that a complete circle is cut before disturbing or removing the cutter.

It will be found upon examination that the rocker arm in some engines shows wear where contact with the valve-stem end is made. Sometimes the wear is crescent shaped and sometimes forms a complete circle. In reassembling the parts, the same alignment of the valve cannot be secured; the valve-stem is likely to strike on the edge of this worn section and the valve to go through a second motion in closing. A shim cannot be inserted with any degree of accuracy and therefore more noise is produced. The only solution is to regrind the rocker arm end. It is to avoid this wear that rollers of hardened steel are used in rocker arm ends where they bear on the valve stems.

Reseating and Truing Valves.—Much has been said relative to valve grinding, and despite the mass of information given in the trade prints it is rather amusing to watch the average repairman or the engine user who prides himself on maintaining his own motor performing this essential operation. The common mistakes are attempting to seat a badly grooved or pitted valve head on an equally bad seat, which is an almost hopeless job, and of using coarse emery and bearing down with all one's weight on the grinding tool with the hope of quickly wearing away the rough surfaces. The use of improper abrasive material is a fertile cause of failure to obtain a satisfactory seating. Valve grinding is not a difficult operation if certain precautions are taken before undertaking the work. The most important of these is to ascertain if the valve head or seat is badly scored or pitted. If such is found to be the case no ordinary amount of grinding will serve to restore the surfaces. In this event the best thing to do is to remove the valve from its seating and to smooth down both the valve head and the

seat in the cylinder before attempt is made to fit them together by grinding. Another important precaution is to make sure that the valve stem is straight, and that the head is not warped out of shape.

A number of simple tools is available at the present time for reseating valves, these being outlined at Fig. 858. That shown at A is a simple fixture for facing off the valve head. The stem is supported by suitable bearings carried by the body or shank of the tool, and the head is turned against

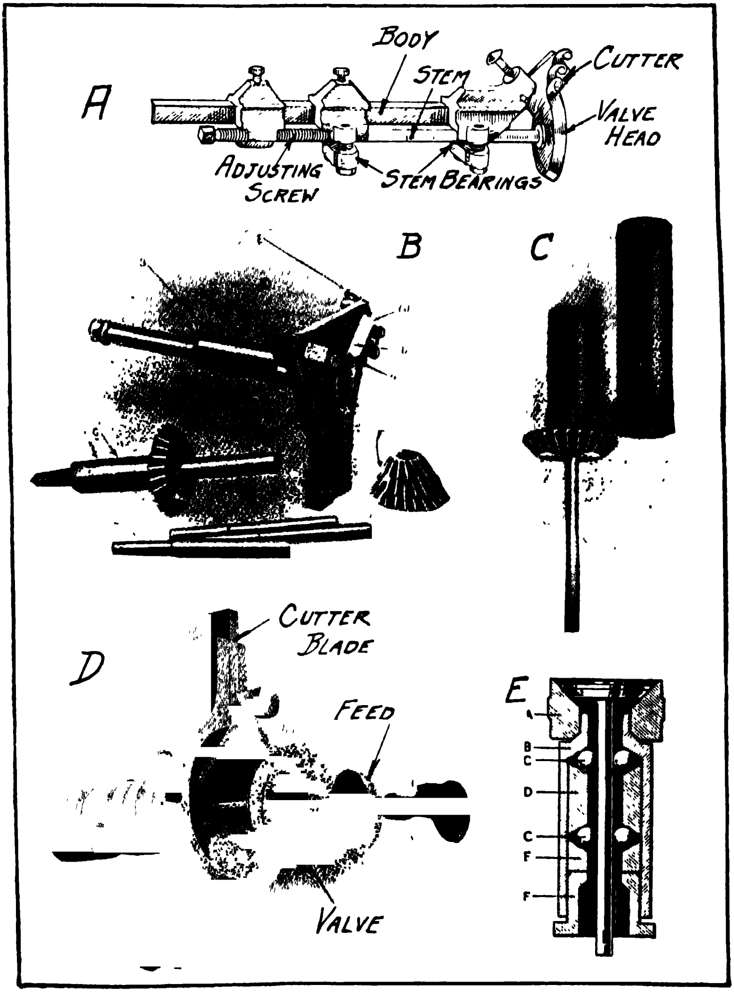


Fig. 858.—Tools for Restoring Valve Head and Seats.

an angularly disposed cutter which is set for the proper valve seat angle. The valve head is turned by a screwdriver, the amount of stock removed from the head depending upon the location of the adjusting screw. Care must be taken not to remove too much metal, only enough being taken off

to remove the most of the roughness. Valves are made in two standard tapers, the angle being either 45 or 60 degrees. It is imperative that the cutter blade be set correctly in order that the bevel is not changed. A set of valve truing and valve-seat reaming cutters is shown at Fig. 858 B. This is adaptable to various size valve heads, as the cutter blade D may be moved to correspond to the size of the valve head being trued up. These cutter blades are made of tool steel and have a bevel at each end, one at 45 degrees, the other at 60 degrees. The valve seat reamer shown at G will take any one of the heads shown at F. It will also take any one of the guide bars shown at H The function of the guide bars is to fit the valve stem bearing in order to locate the reamer accurately and to insure that the valve seat is machined concentrically with its normal center. Another form of valve seat reamer and a special wrench used to turn it is shown at C. The valve head truer shown at Fig. 858 D, is intended to be placed in a vise and is adaptable to a variety of valve head sizes. The smaller valves

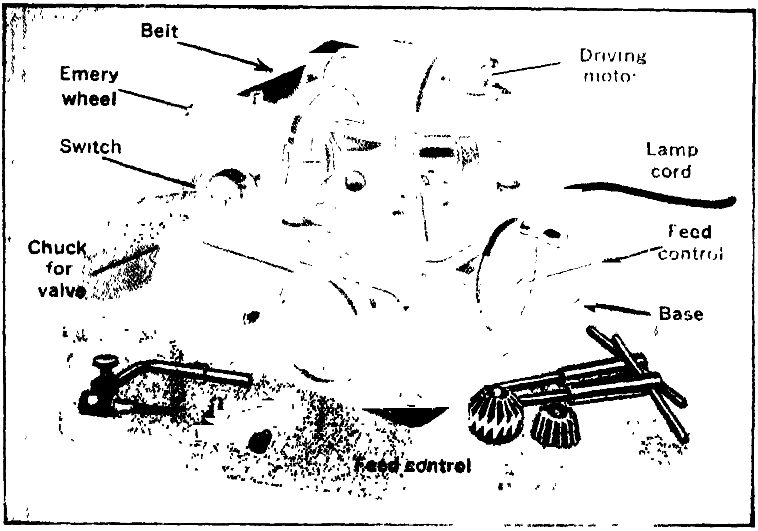


Fig. 859.—Valve Head Grinder for Use with Hard Steel Valves is Motor Driven, Has Variable Feed and Adjustable Chuck to Hold Stems of Various Diameters.

merely fit deeper in the conical depression. The cutter blade is adjustable and the valve stem is supported by a simple self-centering bearing. In operation it is intended that the valve stem, which protrudes through the lower portion of the guide bearing, shall be turned by a drill press or bit stock while the valve head is set against the cutter by pressure of a pad carried at the end of a feed screw which is supported by a hinged bridge member. This can be swung out of place as indicated to permit placing the valve head against the cutter or removing it.

As the sizes of valve heads and stems vary considerably a "Universal" valve head truing tool must have some simple means of centering the valve stem in order to insure concentric machining of the valve head. A valve head truer which employs an ingenious method of guiding the valve stem

is shown at Fig. 858 E. The device consists of a body portion, B, provided with an external thread at the top on which the cutter head, A, is screwed. A number of steel balls, C, are carried in the grooves which may be altered in size by the adjustment nut, F, which screws in the bottom of the body portion, B. As the nut F is screwed in against the spacer member E, the Vee-grooves are reduced in size and the steel balls, C, are pressed out in contact with the valve stem. As the circle or annulus is filled with balls in both upper and lower portions the stem may be readily turned because it is virtually supported by ball bearing guides When a larger valve stem is to be supported, the adjusting nut F, is screwed out which increases the size of the grooves and permits the balls, C, to spread out and allow the larger stem to be inserted Some aviation engine valve heads are made of such hard materials that none of the cutting tools shown, which have been developed for auto engine valves primarily can be used and special valve grinders such as shown at Fig 859 are necessary to restore the valve head. The valve is supported by a special chuck and the face is ground at any desired angle by the rapidly revolving, motor driven emery wheel. Attachments are provided for stems of various diameters. The work carriage may be moved back and forth as well as sideways by independent hand wheel control. The machine shown is made by K R. Wilson, Buffalo, New York, and is made to operate on 60 cycle 110 volt alternating current. Motors wound for other voltages may be obtained.

Valve Grinding Processes.—Mention has been previously made of the importance of truing both valve head and seat before attempt is made to refit the parts by grinding After smoothing the valve seat the next step is to find some way of turning the valve. Automobile valve heads are usually provided with either a screwdriver slot passing through the boss at the top of the valve or with two drilled holes to take a forked grinding tool. A combination grinding tool has been devised which may be used when either the two drilled holes or the slotted head form of valve is to be rotated. This consists of a special form of screwdriver having an enlarged boss just above the blade, this boss serving to support a U-shaped piece which can be securely held in operative position by the clamp screw or which can be turned out of the way if the screwdriver blade is to be used. Aviation engine valves, especially of the tulip form do not have slots or holes and must be turned by the stem end through a special T handle tool or if turned by the head a vacuum cup valve grinder will be essential. This is a rubber suction cup mounted on the end of a long handle, the cup sticking to the valve head.

As it is desirable to turn the valve through a portion of a revolution and back again rather than turning it always in the same direction, a number of special tools has been designed to make this oscillating motion possible without trouble. A simple valve grinding tool is shown at Fig. 860 C. This consists of a screwdriver blade mounted in a handle in such a way that the end may turn freely in the handle. A pinion is securely fastened to the screwdriver blade shank, and is adapted to fit a race provided with a wood handle and guided by a bent bearing member securely fastened to the screwdriver handle. As the rack is pushed back and forth the pinion must be turned first in one direction and then in the other.

A valve grinding tool patterned largely after a breast drill is shown at Fig. 860 D. This is worked in such a manner that a continuous rotation of the operating crank will result in an oscillating movement of the chuck carrying the screwdriver blade. The bevel pinions which are used to turn the chuck are normally free unless clutched to the chuck stem by the sliding sleeve which must turn with the chuck stem and which carries clutching members at each end to engage similar members on the bevel pinions and lock these to the chuck stem, one at a time. The bevel gear carries a campiece which moves the clutch sleeve back and forth as it revolves. This means that the pinion giving forward motion of the chuck is clutched to the chuck spindle for a portion of a revolution of the gear and clutch sleeve is moved back by the cam and clutched to the pinion giving a reverse

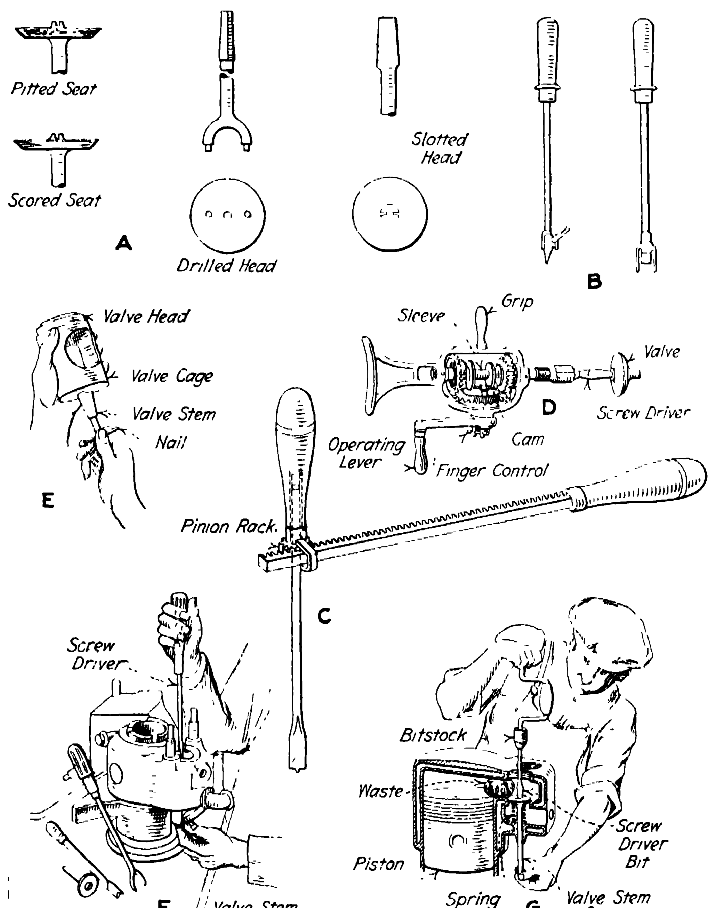


Fig. 860.—Tools and Processes Used in Auto Engine Valve Grinding May Offer Suggestions to Aero Engine Repairmen.

motion of the chuck during the remainder of the main drive gear revolution. A tool of this nature can be used in connection with aviation engines valves by using an extension piece that will hold the valve stem and having another end to fit the chuck, just as the screwdriver blade fits in the sketch.

The usual methods of valve grinding are clearly outlined at Fig. 860 and while automobile motor cylinders are shown the operations are the same in aviation engines if the valve head construction permits of using either a screwdriver blade or a forked end tool to turn it. The view at the left shows the method of turning the valve by an ordinary screwdriver and also shows a valve head having the screwdriver slot for turning the member and two special forms of fork-end valve grinding tools. In the sectional view shown at the right, the use of the light spring between the valve head and the bottom of the valve chamber to lift the valve head from the seat whenever pressure on the grinding tool is released is clearly indicated. It will be noted also that a ball of waste or cloth is interposed in the passage between the valve chamber and the cylinder interior when L head cylinders are used to prevent the abrasive material from passing into the cylinder from the valve chamber but such cylinders are rare in aviation engines. With an I-head cylinder the interior is easily reached for cleaning out all abrasive with gasoline and a compressed air hose. When a bitstock is used, instead of being given a true rotary motion the chuck is merely oscillated through the greater part of the circle and back again. It is necessary to lift the valve from its seat frequently as the grinding operation continues, this is to provide an even distribution of the abrasive material placed between the valve head and its seat. Only sufficient pressure is given to the bitstock to overcome the uplift of the spring and to insure that the valve will be held against the seat. Where the spring is not used it is possible to raise the valve from time to time with the hand which is placed under the valve stem to raise it as the grinding is carried on It is not always possible to lift the valve in this manner when the cylinders are in place on the engine base owing to the space between the valve lift plunger and the end of the valve stem. In this event the use of the spring as shown in sectional view will be desirable.

The abrasive generally used is a paste made of medium or fine emery and lard oil or kerosene or special valve grinding compounds, of which Clover Brand is a good example. This is used until the surfaces are comparatively smooth, after which the final polish or finish is given with a paste of flour emery, grindstone dust, crocus, or ground glass and oil. An erroneous impression prevails in some quarters that the valve head surface and the seating must have a mirror-like polish. While this is not necessary it is essential that the seat in the cylinder and the bevel surface of the head be smooth and free from pits or scratches at the completion of the operation. All traces of the emery and oil should be thoroughly washed out of the valve chamber with gasoline before the valve mechanism is assembled and in fact it is advisable to remove the old grinding compound at regular intervals, wash the seat thoroughly and supply fresh material as the process is in progress.

The truth of seatings may be tested by taking some Prussian blue pigment and spreading a thin film of it over the valve seat. The valve is dropped in place and is given about one-eighth turn with a little pressure

on the tool. If the seating is good both valve head and seat will be covered uniformly with color. If high spots exist, the heavy deposit of color will show these while the low spots will be made evident because of the lack of pigment. The grinding process should be continued until the test shows an even bearing of the valve head at all points of the cylinder seating.

When the valves are held in cages or in detachable cylinder heads as in some marine motors it is possible to catch the cage in a vise and to turn the valve in any of the ways indicated. It is much easier to clean off the emery and oil and there is absolutely no danger of getting the abrasive material in the cylinder if the construction is such that the valve cage or cylinder head member carrying the valve can be removed from the cylinder. When valves are held in cages, the tightness of the seat may be tested by partially filling the cage with gasoline and noticing how much liquid oozes out around the valve head. The degree of moisture present indicates the efficacy of the grinding process A new method of testing valve seatings involves using a rubber cup and pressure gauge over the valve and after pumping in air, to notice how quickly it leaks out.

The valves of Curtiss OX series and most other aviation engine cylinders are easily ground in by using a simple fixture or tool and working from the top of the cylinder instead of from the inside. A tube having a bore just large enough to go over the valve stem is provided with a wooden handle or taped at one end and a hole of the same size as that drilled through the valve stem is put in at the other. To use, the open end of the tube is pushed over the valve stem and a split pin pushed through the tube and stem. The valve may be easily manipulated and ground in place by oscillating in the customary manner. For more modern engines using split retention collars, the end of the grinding tool may be a chuck arrangement and clamp the valve stem by friction. This operation is clearly shown in preceding chapters describing repair processes on specific engine types.

Depreciation in Valve Operating Systems.—There a number of points to be watched in the valve operating system because valve timing may be seriously interfered with if there is much lost motion at the various bearing points in the valve lift mechanism. The two conventional methods of opening valves are shown at Fig. 861. That at A is the type employed when the valves are mounted directly in the head, while the form at B is the system used when the valves are located in a pocket or extension of the cylinder casting as is the case if an L- or T-head cylinder is used as in automobile or marine engine practice. It will be evident that there are several points where depreciation may take place. The simplest form is that shown at B, and even on this there are five points where lost motion may be noted. The periphery of the valve opening cam or roller may be worn, though this is not likely unless the roller or cam has been inadvertently left soft. The pin which acts as a bearing for the roller may become worn, this occurring quite often. Looseness may materialize between the bearing surfaces of the valve lift plunger and the plunger guide casting, and there may also be excessive clearance between the top of the plunger and the valve stem.

On the form shown at Fig. 861 A there are several parts added to those indicated at B. A walking beam or rocker lever is necessary to transform the upward motion of the tappet rod to a downward motion of the valve

stem. The pin on which this member fulcrums may wear as will also the other pin acting as a hinge or bearing for the yoke end of the tappet rod. In various forms, instead of the end of the valve rocker being formed on an arc of a circle and bearing against the stem, the end may be forked and a roller mounted therein. Wear may exist on the pin causing shake or lost motion between the roller and the pin. Ball end pushrods are used on most modern engines and depreciation is easily taken up by the means provided for the purpose, usually consisting of screwing the co-acting ball ends closer together. It will be apparent that if slight play existed at each of the points

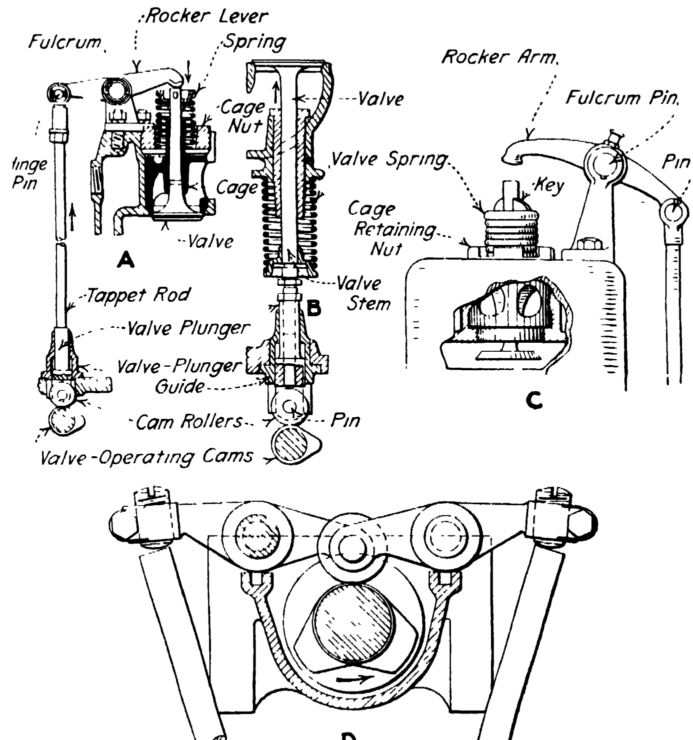


Fig. 861.—Outlining Points in Valve Operating Mechanism of Automotive Engines Where Depreciation is Apt to Exist.

mentioned it might result in a serious diminution of valve opening. Suppose, for example, that there were .005-inch lost motion at each of three bearing points, the total lost motion would be .015-inch or sufficient to produce noisy action of the valve mechanism and appreciably alter valve timing. When valve plungers of the adjustable form, such as shown at B, are used, the hardened bolt head in contact with the end of the valve stem may become hollowed out on account of the hammering action at that point. It is imperative that the top of this member be ground off true and the clearance between the valve

stem and plunger properly adjusted. If the plunger is a nonadjustable type it will be necessary to lengthen the valve stem by some means in order to reduce the excessive clearance. The only remedy for wear at the various hinges and bearing pins is to bore the holes out slightly larger and to fit new hardened steel pins of larger diameter. Depreciation between the valve plunger guide and the valve plunger is usually remedied by fitting new plunger guides in place of the worn ones. If there is sufficient stock in the plunger guide casting as is sometimes the case when these members are not separable from the cylinder casting, the guide may be bored out and bushed with a light bronze bushing but guides are removable in most aviation engines and can be replaced with new.

A common cause of irregular engine operation is due to a sticking valve as shown at Fig. 861 C. This may be owing to a bent valve stem, a weak or broken valve spring if a single spring is used, or an accumulation of burnt or gummed oil between the valve stem and the valve stem guide. In order to prevent this the valve stem must be smoothed with fine emery cloth and no burrs or shoulders allowed to remain on it, and the stem must also be straight and at right angles to the valve head. If the spring is weak it may be strengthened in some cases by stretching it out after annealing so that a larger space will exist between the coils and re-hardening. Obviously if a spring is broken the only remedy is replacement of the defective member and the writer strongly urges the replacement of any weak spring or springs with new ones. The popular method of overhead valve actuation in aviation engines is that shown at Fig. 861 D. Rocker arms carry rollers at one end to ride the cam and an adjusting screw at the other. Wear can exist at the rocker fulcrum bearings and between the roller and its pin on the cam end.

Mention has been made of wear in the valve stem guide and its influence on engine action. When these members are an integral part of the cylinder as in some of the cheaper auto engines the only method of compensating for this wear is to drill the guide out and fit a bushing, which may be made of steel tube. In aero engines, especially those of recent development, the valve stem guide is driven or screwed into the cylinder or head casting and is a separate member which may be removed when worn and replaced with a new one. When the guides become enlarged to such a point that considerable play exists between them and the valve stems, they may be easily knocked out or unscrewed and replaced with new.

Piston Troubles.—If an engine has been entirely dismantled it is very easy to examine the pistons for deterioration. While it is important that the piston be a good fit in the cylinder it is mainly upon the piston rings that compression depends. The piston should fit the cylinder with but little looseness, usual practice being to have a cast iron piston about .001-inch smaller than the bore for each inch of piston diameter at the point where the least heat is present or at the bottom of the piston. It is necessary to allow more than this at the top of the piston owing to its expansion due to the direct heat of the explosion. The clearance is usually graduated and a piston that would be .005-inch smaller than the cylinder bore at the bottom would be about .0065-inch at the middle and .0075-inch at the top. If much more play than this is evidenced the piston will "slap" in the cylinder and the piston will be worn at the ends more than in the center.

Aluminum or alloy pistons require more clearance than cast iron ones do, usually 1.50 times as much. Pistons sometimes warp out of shape and are not truly cylindrical, especially in the trunk types which are not relieved around the piston bosses. This results in the high spots rubbing on the cylinder while the low spots will be blackened where a certain amount of gas has leaked by. If the piston is not scratched too deeply, or the blackened areas do not extend from top to bottom, they may be replaced after cleaning off the roughness. If worn so that there is considerable slap in the cylinder, the only remedy is replacement with members of the proper size. A piston should be carefully examined for wear at the wristpin bosses if the pin is a floating type and also for cracks in the skirt or head.

Mention has been previously made of the necessity of reboring or regrinding a cylinder that has become scored or scratched and which allows the gas to leak by the piston rings. When the cylinder is ground out, it is necessary to use a larger piston to conform to the enlarged cylinder bore. Most manufacturers are prepared to furnish over-size pistons, there being four standard over-size dimensions adopted by the S. A. E. for rebored cylinders. These are .010-inch, .020-inch, .030-inch, and .040-inch larger than the original bore

The piston rings should be taken out of the piston grooves and all carbon deposits removed from the inside of the ring and the bottom of the groove. It is important to take this deposit out because it prevents the rings from performing their proper functions by reducing the ring elasticity, and if the deposit is allowed to accumulate it may eventually result in sticking and binding of the ring, this producing excessive friction or loss of compression. When the rings are removed they should be tested to see if they retain their elasticity. If gas has been blowing by the ring or if these members have not been fitting the cylinder properly the points where the gas passed will be evidenced by burnt, brown or roughened portions of the polished surface of the pistons and rings. The point where this discoloration will be noticed more often is at the thin end of an eccentric ring, the discoloration being present for about ½ inch or ¾ inch each side of the slot. It may be possible that the rings were not true when first put in. This made it possible for the gas to leak by in small amounts initially which increased due to continued pressure until quite a large area for gas escape had been created. Practically all aviation engines now use concentric piston rings and as various types of compression, oil control, quick-seating and compound rings have been fully considered in the chapter on pistons and rings, it is not necessary to go into this subject again.

Piston Ring Manipulation.—Removing piston rings without breaking them is a difficult operation if the proper means are not taken, but is a comparatively simple one when the trick is known. The tools required are very simple, being three strips of thin steel about one-quarter inch wide and four or five inches long and a pair of spreading tongs made up of one-quarter inch diameter keystock tied in the center with a copper wire to form a hinge. The construction is such that when the hand is closed and the handles brought together the other end of the expander spreads out, an action just opposite to that of the conventional pliers. The method of using the tongs and the metal strips is clearly indicated at Fig. 862. At A

the ring expander is shown spreading the ends of the rings sufficiently to insert the pieces of sheet metal between one of the rings and the piston. Grasp the ring as shown at B, pressing with the thumbs on the top of the piston and the ring will slide off easily, the thin metal strips acting as guide members to prevent the ring from catching in the other piston grooves. Usually no difficulty is experienced in removing the top or bottom rings, as these members may be easily expanded and worked off directly without

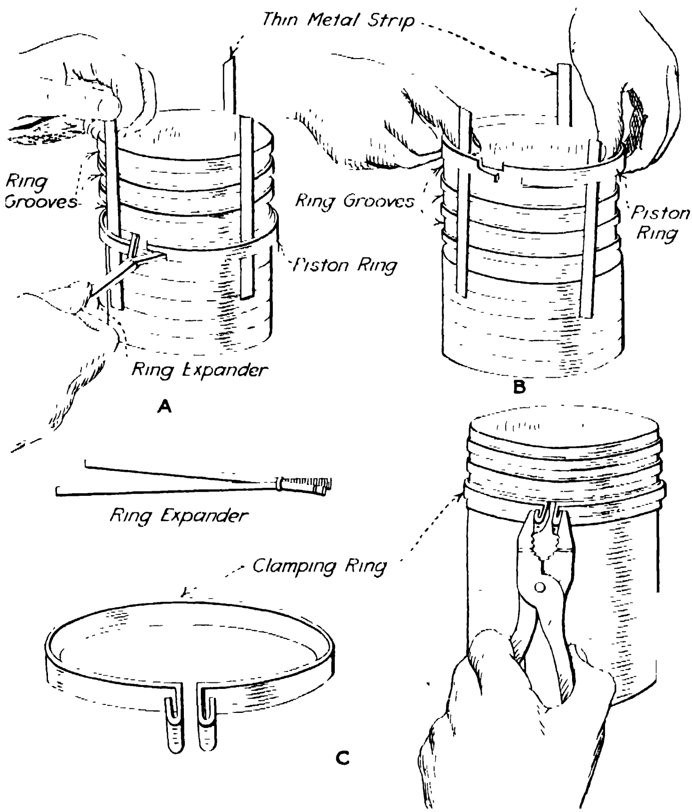


Fig. 862.—Method of Removing Piston Rings and Simple Clamp to Facilitate Insertion of Rings in Cylinder Bore. A—How to Use Expander. B—Metal Strips to Permit Working Ring Over Piston Grooves. C—Clamp for Compressing Rings and its Use.

the use of a metal strip. When removing the intermediate rings, however, the metal strips will be found very useful. These are usually made by the repairman by grinding the teeth from old hacksaw blades and rounding the edges and corners in order to reduce the liability of cutting the fingers. By the use of the three metal strips a ring is removed without breaking or distorting it and practically no time is consumed in the operation.

Fitting Piston Rings.—Before installing new rings, they should be carefully fitted to the grooves to which they are applied. The tools required

are a large piece of fine emery cloth, a thin, flat file, a small vise with copper or leaden jaw clips, and a smooth hard surface such as that afforded by the top of a surface plate or a well planed piece of hard wood. After making sure that all deposits of burnt oil and carbon have been removed from the piston grooves, three rings are selected, one for each groove. The ring is turned all around its circumference into the groove it is to fit, which can be done without springing it over the piston as the outside edge of the ring may be used to test the width of the groove just as well as the inside edge. The ring should be a fair fit and while free to move circumferentially there should be no appreciable up and down motion. If the ring is a tight fit it should be laid edge down upon the piece of emery cloth which is placed on the surface plate and carefully rubbed down until it fits the groove it is to occupy. It is advisable to fit each piston ring individually and to mark them in some way to insure that they will be placed in the groove to which they are fitted.

The repairman next turns his attention to fitting the ring in the cylinder itself. The ring should be pushed into the cylinder at least two inches up from the bottom and endeavor should be made to have the lower edge of the ring parallel with the bottom of the cylinder. If the ring is not of correct diameter, but is slightly larger than the cylinder bore, this condition will be evident by the angular slots of the rings being out of line or by difficulty in inserting the ring if it is a lap joint form. If such is the case the ring is removed from the cylinder and placed in the vise between soft metal jaw clips. Sufficient metal is removed with a fine file from the edges of the ring at the slot until the edges come into line and a slight space exists between them when the ring is placed into the cylinder. It is important that this space be left between the ends, for if this is not done when the ring becomes heated the expansion of metal may cause the ends to abut and the ring to jam in the cylinder. The piston ring gap depends on the type and size of the engine and is usually given in the engine manufacturer's tolerances and clearances table.

It is necessary to use more than ordinary caution in replacing the rings on the piston because they are usually made of cast iron, a metal that is very fragile and liable to break because of its brittleness. Special care should be taken in replacing new rings as these members are more apt to break than old ones which are seasoned. This is probably accounted for by the heating action on used rings which tends to anneal the metal as well as making it less springy. The bottom ring should be placed in position first which is easily accomplished by springing the ring open enough to pass on the piston and then sliding it into place in the lower groove which on some types of engines is below the wristpin, whereas in others all grooves are above that member. The other members are put in by a reversal of the process outlined at Fig. 862 A and B. It is not always necessary to use the guiding strips of metal when replacing rings as it is often possible, by putting the rings on the piston a little askew and maneuvering them to pass the grooves without springing the ring into them. The top ring should be the last one placed in position.

Before placing pistons in the cylinder one should make sure that the slots in the piston rings are spaced equidistant on the piston, and if pins are used to keep the ring from turning one should be careful to make sure

that these pins fit into their holes in the ring and that they are not under the ring at any point. Practically all cylinders are chamfered at the lower end to make insertion of piston rings easier. The operation of putting on a cylinder casting over a piston really requires two pairs of hands, one to manipulate the cylinder, the other person to close the rings as they enter the cylinder. This may be done very easily by a simple clamp member made of sheet brass or iron and used to close the ring as indicated at Fig. 862 C. It is apparent that a narrow clamp must be adjusted to each individual ring and that the split portion of the clamp must coincide with the split portion of the ring. Wider clamps that will embrace all rings and provided with a bolt to hold the lips together and the ring contracted are sometimes used. The cylinder should be well oiled before any attempt is made to install the pistons. The engine should be run with more than the ordinary amount of lubricant for several hours after new piston rings have been inserted. On first starting the engine, one may be disappointed in that the compression is even less than that obtained with the old rings. This condition will soon be remedied as the rings become polished and adapt themselves to the contour of the cylinder.

Wristpin Wear.—While wristpins are usually made of very tough steel, case hardened with the object of wearing out an easily renewable bronze bushing in the upper end of the connecting rod rather than the wristpin it sometimes happens that these members will be worn so that even the replacement of a new bushing in the connecting rod will not reduce the lost motion and attendant noise due to a loose wristpin. The only remedy is to fit new wristpins to the piston. Where the connecting rod is clamped to the wristpin and that member oscillates in the piston bosses the wear will usually be indicated on bronze bushings which are pressed into the piston bosses of cast iron pistons though when alloy is used, the wristpins usually bear directly in the metal. These are easily renewed and after running a reamer through them of the proper size no difficulty should be experienced in replacing either the old or a new wristpin depending upon the condition of that member. If no bushings are provided, as in alloy pistons, the bosses can sometimes be bored out and thin bushings inserted, though this is not always possible. The alternative is to ream or grind out the bosses and upper end of rod a trifle larger after holes are trued up and fit oversize wristpins.

Inspecting Crankshaft and Crankcase.—The crankshaft, after the propeller hub has been removed, should be put between centers to check the trueness of the shaft end and to determine whether or not the shaft is sprung. Main bearings and connecting rod or crankpins should be measured for amount of wear, or indicated with a dial or special test-indicator. Crankpin bearings that are out-of-parallel with the main bearings throw the connecting rods out-of-line, causing them to whip back and forth between the piston-pin bosses, producing probably 50 per cent of the noise usually attributed to piston slap This lack of parallelism can best be determined by the use of a special crankshaft testing machine, with parallelograph attachment, which draws a picture showing the exact condition of the pins relative to the main bearings

The crankcase should be checked up for cracks, alignment and warpage

of the base. All cylinder-block and journal-bearing studs should be examined for poor threads or looseness in the crankcase. Camshafts, camshaft bushings in the crankcase, timing-gears, idler gears, idler-gear studs, idler-gear bushings, and magneto and water-pump-shaft bushings and bearings should be checked to determine whether new ones are required. Connecting rods should be examined for fractures and all bolts and nuts should be given special attention.

Worn timing-gears are always more or less noisy, and, while the old ones may frequently be used in a reconditioning job, this should never be done without a clear understanding with the owner, who may not place as high value on quietness as is represented in the cost of new gears. Idler-gear studs may be saved by grinding off 0.002 inch from the outside diameter, as the new bushings usually have enough metal inside to allow for an undersized stud.

Inspection and Refitting of Engine Bearings.—While the engine is dismantled one has an excellent opportunity to examine the various bearing points in the engine crankcase to ascertain if any looseness exists due to depreciation of the bearing surfaces. As will be evident, both main crankshaft bearings and the lower end of the connecting rods may be easily examined for deterioration. With the rods in place, it is not difficult to feel the amount of lost motion by grasping the connecting rod firmly with the hand and moving it up and down. After the connecting rods have been removed and the propeller hub taken off the crankshaft to permit of ready handling, any looseness in the main bearing may be detected by lifting up on either the front or rear end of the crankshaft and observing if there is any lost motion between the shaft journal and the main bearing caps. It is not necessary to take an engine entirely apart to examine the main bearings, as in most forms these may be readily reached by removing the sump. The symptoms of worn main bearings are not hard to identify. If an engine knocks regardless of speed or spark-lever position, and the trouble is not due to detonation because of unsuitable fuel or carbon deposits in the combustion-chamber, one may reasonably surmise that the main bearings have become loose or that lost motion may exist at the connecting rod big ends, and possibly at the wristpins. The main journals of any well designed engine are usually proportioned with ample surface and will not wear unduly unless lubrication has been neglected. The connecting rod bearings wear quicker than the main bearings owing to being subjected to a greater unit stress, and it may be necessary to take these up or replace the bearing metal.

Adjusting Main Bearings.—When the bearings are not worn enough to require refitting the lost motion can often be eliminated by removing one or more of the thin shims or liners ordinarily used to separate the bearing caps from the seat. These are shown at Fig. 863. Care must be taken that an even number of shims of the same thickness are removed from each side of the journal. Shims are not used in aviation engines as much as they are in automobile motors and in most cases the brasses must be replaced with new when worn. If there is considerable lost motion after one or two shims have been removed, it will be advisable to take out more shims and to scrape the bearing to a fit before the bearing cap is tightened up. It may

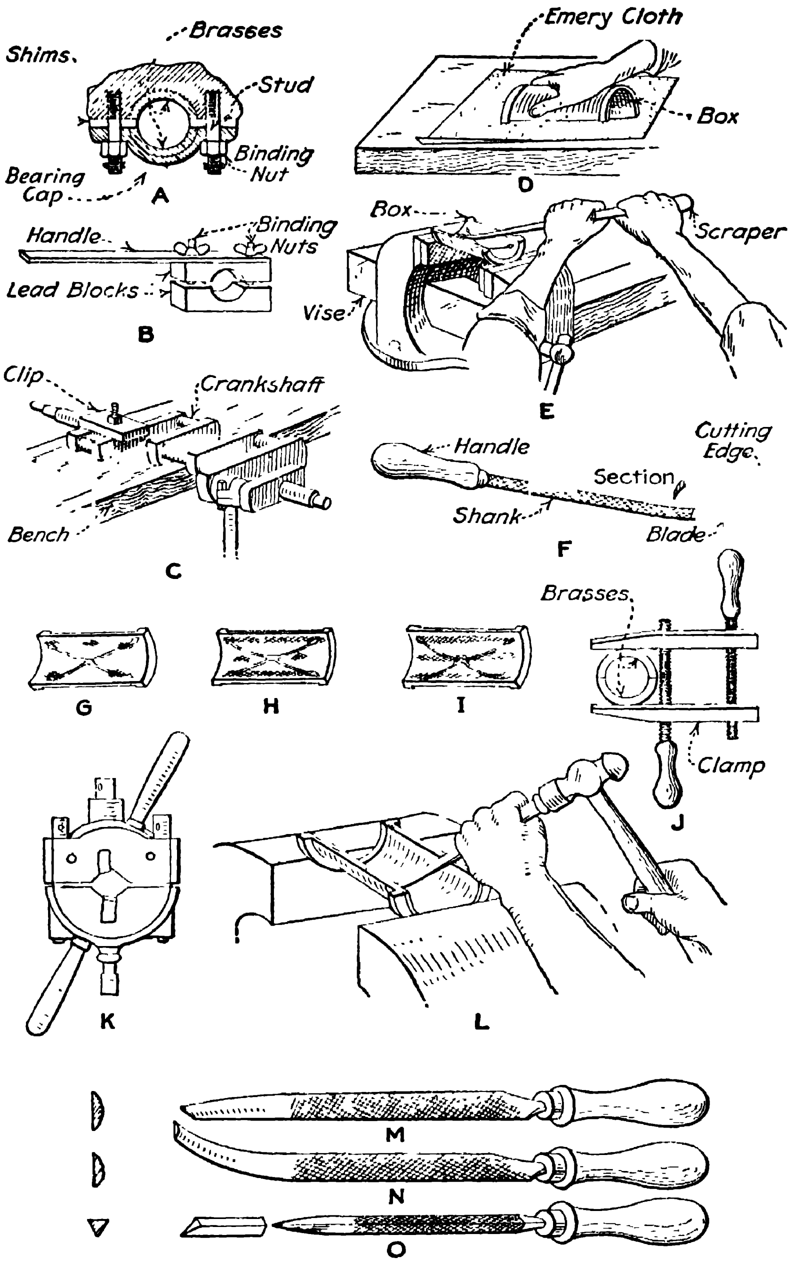


Fig. 863.—Tools and Processes Used in Refitting Engine Bearings.

be necessary to clean up the crankshaft journals as these may be scored due to not having received clean oil or having had bearings seize upon them. It is not difficult to true up the crankpins or main journals if the score marks are not deep. A fine file and emery cloth may be used, or a lapping tool such as depicted at Fig. 863 B. The latter is preferable because the file and emery cloth will only tend to smooth the surface while the lap will have the effect of restoring the crank to proper contour. A badly grooved shaft can only be restored properly by the use of a special crankshaft grinding machine, but minor grooves can be removed by careful lapping. Grinding is the only process to restore out-of-round crankpins or main journals.

A lapping tool may be easily made, as shown at B, the blocks being of lead or hard wood. As the width of these are about half that of the crankpin the tool may be worked from side to side as it is rotated. An abrasive paste composed of fine emery powder and oil is placed between the blocks, and the blocks are firmly clamped to the crankpin. As the lead blocks bed down, the wing nut should be tightened to insure that the abrasive will be held with some degree of pressure against the shaft. A liberal supply of new abrading material is placed between the lapping blocks and crankshaft from time to time and the old mixture cleaned off with gasoline. It is necessary to maintain a side to side movement of the lapping tool in order to have the process affect the whole width of the crankpin equally. The lapping is continued until a smooth surface is obtained. If a crankpin is worn out of true to any extent the only method of restoring it is to have it ground down to proper circular form by a competent mechanic having the necessary machine tools to carry on the work accurately. A crankpin truing tool that may be worked by hand is shown at Fig. 187 K, this being suited for crankpins that are not hardened or made of hard alloy steels. It shaves off the metal of the high spots, the amount of cut being adjustable by screwing the cutter in or out.

After the crankshaft is trued the next operation is to fit it to the main bearings or rather to scrape these members to fit the shaft journal. In order to bring the brasses closer together, it may be necessary to remove a little metal from the edges of the caps to compensate for the lost motion. A very simple way of doing this is shown at Fig. 863 D. A piece of medium emery cloth is rested on the surface plate and the box or brass is pushed back and forth over that member by hand, the amount of pressure and rapidity of movement being determined by the amount of metal it is necessary to remove. This is better than filing, because the edges will be flat and there will be no tendency for the bearing caps to rock when placed against the bearing seat. It is important to take enough off the edges of the boxes to insure that they will grip the crank tightly. The outer diameter must be checked with a pair of calipers during this operation to make sure that the surfaces remain parallel. Otherwise, the bearing brasses will only grip at one end and with such insufficient support they will quickly work loose, both in the bearing seat and bearing cap.

Scraping Brasses to Fit.– To insure that the bearing brasses will be a good fit on the trued-up crankpins or crankshaft journals, they must be scraped to fit the various crankshaft journals. The process of scraping, while a tedious one, is not difficult, requiring only patience and some degree

of care to do a good job. The surface of the crankpin is smeared with Prussian blue pigment which is spread evenly over the entire surface. The bearings are then clamped together in the usual manner with the proper bolts, and the crankshaft revolved several times to indicate the high spots on the bearing cap At the start of the process of scraping in, the bearing may seat only at a few points as shown at Fig 863 G Continued scraping will bring the bearing surface as indicated at H, which is a considerable improvement, while the process may be considered complete when the brass indicates a bearing all over as at I. The high spots are indicated by blue, as where the shaft does not bear on the bearing there is no color. The high spots are removed by means of a scraping tool of the form shown at Fig. 863 F, which is easily made from a worn-out file. These are forged to shape and ground hollow as indicated in the section, and are kept properly sharpened by frequent rubbing on an ordinary oil stone. To scrape properly, the edge of the scraper must be very keen. The straight and curved half-round scrapers, shown at M and N, are used for bearings. The three-cornered scraper, outlined at O, is also used on curved surfaces, and is of value in rounding off sharp corners The straight or curved half-round type works well on soft-bearing metals, such as babbitt, or white brass, but on yellow brass or bronze it cuts very slowly, and as soon as the edge becomes dull considerable pressure is needed to remove any metal, this calling for frequent sharpening.

When correcting errors on flat or curved surfaces by hand-scraping, it is desirable, of course, to obtain an evenly spotted bearing with as little scraping as possible. When the part to be scraped is first applied to the surface-plate, or to a journal in the case of a bearing, three or four "high" spots may be indicated by the marking material The time required to reduce these high spots and obtain a bearing that is distributed over the entire surface depends largely upon the way the scraping is started. If the first bearing marks indicate a decided rise in the surface, much time can be saved by scraping larger areas than are covered by the bearing marks; this is especially true of large shaft and engine bearings, etc. An experienced workman will not only remove the heavy marks, but also reduce a larger area; then, when the bearing is tested again, the marks will generally be distributed somewhat. If the heavy marks which usually appear at first are simply removed by light scraping, these "point bearings" are gradually enlarged, but a much longer time will be required to distribute them.

The number of times the bearing must be applied to the journal for testing is important, especially when the box or bearing is large and not easily handled. The time required to distribute the bearing marks evenly depends largely upon one's judgment in "reading" these marks. In the early stages of the scraping operation, the marks should be used partly as a guide for showing the high areas, and instead of merely scraping the marked spot the surface surrounding it should also be reduced, unless it is evident that the unevenness is local. The idea should be to obtain first a few large but generally distributed marks; then an evenly and finely spotted surface can be produced quite easily.

In fitting brasses when these are of the removable type, two methods may be used. The upper half of the engine base may be inverted on a suitable bench or stand and the boxes fitted by placing the crankshaft in position, clamping down one bearing cap at a time and fitting each bearing in succession until they bed equally. From that time on the bearings should be fitted at the same time so the shaft will be parallel with the bottom of the cylinders. Considerable time and handling of the heavy crankshaft may be saved if a preliminary fitting of the bearing brasses is made by clamping them together with a carpenter's wood clamp as shown at Fig. 863 J, and leaving the crankshaft attached to the bench as shown at C. The brasses are revolved around the crankshaft journal and are scraped to fit wherever high spots are indicated until they begin to seat fairly. When the brasses assume a finished appearance the final scraping should be carried on with all bearings in place and revolving the crankshaft to determine the area of the seating When the brasses are properly fitted they will not only show a full bearing surface, but the shaft will not turn unduly hard if revolved with a moderate amount of leverage.

Bearings of white metal or babbitt can be fitted tighter than those of bronze, and care must be observed in supplying lubricant as considerably more than the usual amount is needed until the bearings are run in by several hours of test block work. Before the scraping process is started it is well to chisel an oil groove in the bearing as shown at Fig. 863 L. Grooves are very helpful in insuring uniform distribution of oil over the entire width of bearing and at the same time act as reservoirs to retain a supply of oil but they must be cut in with considerable judgment. The tool used is a round-nosed chisel, the effort being made to cut the grooves of uniform depth and having smooth sides. Care should be taken not to cut the grooves too deeply or make them too long as this will seriously reduce the strength of the bearing bushing. The shape of the groove ordinarily provided is clearly shown at Fig. 863 G, and it will be observed that the grooves do not extend clear to the edge of the bearing, but stop about a quarter of an inch from that point. The hole through which the oil is supplied to the bearing is usually drilled in such a way that it will communicate with the groove. The designers of some modern engines do not provide any grooves at all, others very short grooves. A safe rule to follow in grooving is to duplicate those provided in the original bearings.

The tool shown at Fig. 863 K, is of recent development, and is known as a "crankshaft equalizer." This is a hand-operated turning tool, carrying cutters which are intended to smooth down scored crankpins without using a lathe. The feed may be adjusted by suitable screws and the device may be fitted to crankpins and shaft-journals of different diameters by other adjusting screws. This device is not hard to operate, being merely clamped around the crankshaft in the same manner as the lapping tool previously described, and after it has been properly adjusted it is turned around by the levers provided for the purpose, the continuous rotary motion removing the metal just as a lathe tool would. While it has been devised for automobile motors, it may be used on aviation crankshafts where the metal is soft enough to permit its use.

Remetaling Babbitt Bearings.—The operation of remetaling babbitt bearings is by no means a simple one; each step must be well understood

and properly performed to obtain the best results. Experience has shown that a perfectly good babbitt can be made practically worthless for bearings by allowing it to become too hot, also by pouring when too hot or too cold, yet sufficient attention is not given in many instances to the proper handling of the babbitt in melting and applying it to the bearing according to Mr. E. Andrews, writing on this subject in *Power*.

To renew babbitt bearings effectively, it is necessary to remove all the old lining from the shell by heating, preferably in a pot of molten scrap babbitt kept at a temperature of about 675 degrees Fahrenheit. Immediately the old lining is melted out, swab the bearing surface with zinc chloride and then dip the shell into a pot of molten "half-and-half" solder, which should be kept at a temperature not less than 625 and not more than 675 degrees Fahrenheit. Babbitt metal should not be used for tinning because it has a much higher melting point, which makes it difficult to maintain a molten film on the bearing surfaces. The shell should be left in the molten solder until it is just hot enough for the solder to run off freely, leaving a thin coating on the surface. The above applies to steel or bronze shells and not to any construction where white metal is poured directly into Dural or other aluminum alloy caps or connecting rod big ends. In such cases, anchorage holes must be drilled into the alloy to hold the babbitt.

Occasionally, it is found when a bearing lining has been melted out, that the surface contains black spots or streaks; these should be removed by scraping or filing before tinning the shell. When the bearing surface is properly cleaned, cover the parts not to be tinned with claywash or a thin mixture of graphite and water. Swab the bearing surfaces with the zinc chloride and then tin the shell by immersing in the molten solder. The best material for wiping the shell bearing surface is closely woven cotton fabric that is free from nap. Ordinary cotton waste is unsatisfactory, as it tends to leave strands upon the tinned surface, which are difficult to remove. The bearing to be babbitted should be done immediately after it has been tinned before losing the heat given to it during the latter process.

Dealing now with the babbitt metal itself, care must be taken not to overheat it during the melting operation, as an overheated babbitt is more or less brittle. The correct temperature is from 850 to 875 degrees Fahrenheit. It is necessary that this temperature be maintained when pouring the metal and that the higher temperature be not exceeded. Before pouring, the molten metal must be thoroughly stirred, preferably with a stick of wood; otherwise the heavy metals will settle at the bottom of the pot. To prevent oxidation of the molten metal, cover it with a thin layer of powdered charcoal. A rough approximation that the babbitt metal is hot enough to pour is that point where the stick chars and just bursts into flame.

Wherever practicable the bearing shell should be in a vertical position while pouring. The bearing should be mounted in a jig and both heated until the tinning on the inner surface just begins to run. Pour from the ladle in a steady stream directly down along the heated mandrel to avoid pocketing of air or splashing. A well-designed ladle for the job is one having a rounded spout to enable the babbitt to be poured in a round and

smooth stream. If the lip of an ordinary ladle is used with rough burrs or other surface irregularities, the metal is splashed up against the mandrel, which tends to produce porous surfaces or blowholes. Properly remetaled bearings should ring when struck lightly with a hammer; if they do not, it indicates that the babbitt metal has not adhered thoroughly or that the bearing is cracked. Only the highest grade nickel babbitt metal should be used in aviation engines. The ordinary grades suited for machinery bearings is not suited for engines.

There is a tendency among a good many mechanics to cut a lot of grooves in a bearing on the assumption that the more grooves there are, the more lubrication the bearing gets and the less likely it is to heat. Then there seems to be a tendency among other mechanics with an artistic temperament, to cut the grooves in fanciful designs. Grooving should be done with the utmost economy because, at its best, a groove is a necessary evil. Every groove cut in a bearing means so much less surface area and weakens the bearing to that extent. The edges should be rounded off, otherwise the sharp edges are likely to wipe off the oil and cause the bearing to heat. After a period of use it is well to examine the bearing to see whether the wear on the babbitt has again sharpened the edges of the grooves or closed them. In sectional bearings the inside edges should be grooved away where the sections meet. Improper grooving may entirely change the pressure lubricating system and it is a good rule to observe the grooving provided by the engine builder and this should be followed even if it does not agree with the notions or previous experience of the mechanic doing the work. The mandrels used in babbitt pouring jigs are always smaller than the shaft the brasses are to fit and the bearing must be fitted by boring, line reaming or hand scraping to fit and sometimes by the three processes, one following the other in the order named, the final fitting being by very light hand scraping to remove high spots, though boring and line reaming usually leaves a good enough finish if carefully done so the final polish is given by the running in process.

Fitting Bearings by Boring.—Before inserting bearing halves in the crankcase bores, particular care should be taken to see that everything is clean and that no chips or burrs on bearings are allowed to get in between the bore and the outside of the bearing halves, which should be forced into the bores as lightly as possible. It should be borne in mind that the difference between fitting bearings into a new and an old crankcase is a vast one. The bores in a new crankcase are round and true, while in an old one it is difficult to determine what shape they are in. It should also be remembered that the builder of the engine had a manufacturing tolerance in machining the bores of the crankcase and the bearing manufacturer must also have tolerance on the outside diameter of the bearings. For example, if the crankcase bore should happen to be 0.002 inch over standard and the outside diameter of the bearing should be 0.002 inch minus standard, the bearing would then come in contact with the bore only at the very bottom, leaving an opening of 0.002 inch at each side of the bearing at the top. Should the conditions be reversed, that is, the crankcase bore be under standard and the outside diameter of the bearing over standard, the bearing would touch on the sides at the top, leaving an opening at the bottom

of the bore. In either case the bearing would soon work loose and give trouble. Not only the manufacturers' tolerances are to be considered, but also the wear and warpage of the crankcase bore, and to compensate for these inaccuracies, it is of the utmost importance that the bearing halves be left 0.002 to 0.003 inch above the crankcase and the cap faces, so that when bolting the cap on the crankcase the faces of the bearing halves will meet before the faces of the cap and the crankcase, thus giving the bearings what is known as a "drive fit," similar to that of a connecting-rod pin-bushing. The fitting of bearings into the crankcase should never be attempted before the block, or blocks, have first been bolted on the case.

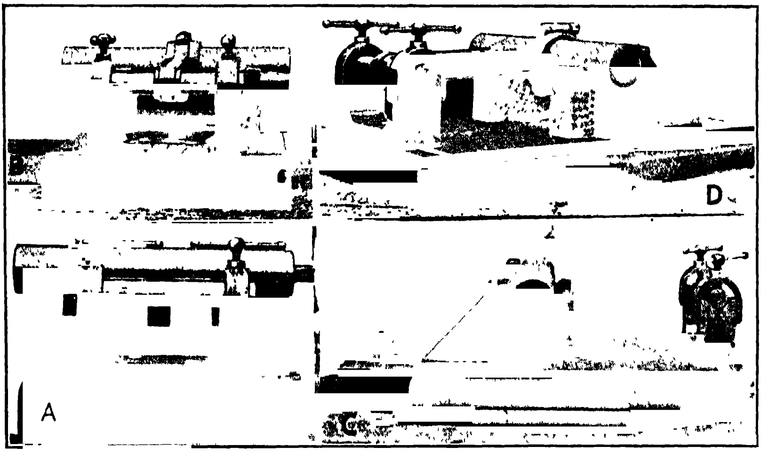


Fig. 864.—Special Jig for Aligning Connecting Rods of Curtiss OX Series Motors Can be Used for Other Rods Within its Capacity by Using Suitable Mandrels.

This brings the crankcase bores into permanent alignment with the cylinder base and, unless the cylinders and the crankcases are thus assembled before fitting the bearings, no assurance of accuracy is possible.

Having properly fitted the bearings into the crankcase, they should be carefully removed, the bearing fixture clamped on the crankcase and the boring tools located from the bores. This operation has been described in the chapter on overhauling Curtiss D12 engines. The bearings can then be replaced in the crankcase and bored to the size of the crankshaft, plus 0.001 inch per inch of diameter for an oil-film. Thrust bearings in the crankcase should next be fitted and as much care should be exercised in securing squareness of the face of the thrusts as in securing accuracy of the diameter of the bearing bore. Before removing the bearing caps after boring and to insure absolute accuracy and uniformity in the resetting of the caps, when putting in the crankshaft, it is recommended that each nut be carefully marked in relation to its stud and that they be brought to exactly the same relation in the final assembly.

The same boring method is used in fitting the connecting-rod bearings. Piston-pins should be fitted in the connecting rods before the bearings are fitted, and the squareness and twist of the rods checked-up both before and after the boring of the bearings by special fixtures as shown at Fig.

864. This shows a jig adapted for OX engine rods but it can be used for others by employing proper mandrels. Sides of the bearings require as much care as the face, as excessive end clearance on the connecting-rod bearing reduces oil pressure and prevents an even distribution of lubricant throughout the engine. Too much clearance will also soon result in a noisy engine, caused by the connecting rod sliding back and forth on the pins and striking against the sides of the crankshaft and also the piston pin boss.

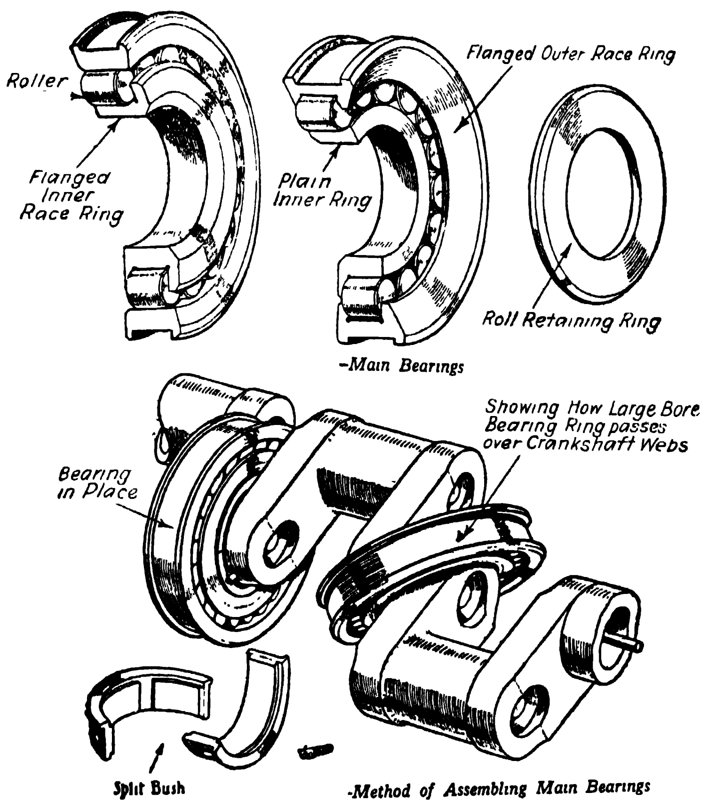


Fig. 865.—Roller Bearings Used on Napier "Lion" Engine Crankshaft and How Intermediate Bearings May be Removed Over Crankwebs.

Assembling Main Roller Type Bearings to Crankshaft.—In fitting Nos. two, three and four bearings on Napier-Lion engines, the split bushes are first prepared and fitted, together with the keys for the keyed half of the bush. In order to ensure a satisfactory fit for the bearing when assembled a certain amount of selection of both bearings and split bushes is recom-

mended where circumstances permit normally a bush or tap limit of thickness is used with a journal on low limit of diameter and vice versa. The sharp corners of the bushes must be radiused and a good lead given to the leading edge of the bore of the bush, the chamfer at each end of the brush being well blended into the bore. The leading edge of each bearing journal, i.e., leading relative to the split bush when fitting must be given a slight radius to blend to the crankweb. It may be found that the ends of the split bushes foul on the webs where they blend to the journals. If this is so a small depression may be filled in the web, using a round or half round, file of small size, removing just enough metal to allow the bush to pass freely with its bore parallel to and in contact with the journal. If this is not done, the bush will enter the bearing at an angle, and if driven home will damage either the journal or bearings, or both. The bushes should now be tried on the bearings using marking to verify that they seat correctly, particular attention being paid to the radii of the webs and corresponding chamber on the split bushes. The keyed half of the split bush must be made a good push fit on the key assembling.

It is recommended that the following sequence be followed in assembling the bearings on the crankshaft:

1. Fit No. 5, i.e., front main bearing. The inner race is heated in oil at 100 degrees Centigrade and then placed in position on the shaft, care being taken that the chamfer in the bore of the inner race coincides with the radius on the web. A certain amount of selection may be necesary here in order to get the most satisfactory fit. The rollers are then assembled on the inner race, being held in position by means of a narrow belt of leather, or other suitable material, and the outer race fitted. There should be not less than .002 inch diametric clearance between rollers and outer race.

2. Fit oil thrower to pinion putting setscrews loosely in position. It may be found necessary to ease the bore of the thrower slightly by means of a scraper. Place keys in position on shaft and assemble pinion with nut and locking washer. The nut is driven up with a spanner and lead hammer until the distance between the shoulder on No. 4 crank throw front web and the rear face of the pinion boss is approximately 1.175 inches. The nut is left in such a position that the tab of the locking washer is central on one of the flats.

Tighten up oil-thrower setscrews until the thrower is firmly held against the face of the inner race of No. 5 bearing, the screws being locked either by means of a single length of $\frac{1}{16}$ inch diameter mild steel wire, threaded through both screws or in the Series 5 type by means of the spring and locking plate.

3. The remaining main bearings are next assembled in the sequence 4, 3, 2, 1. Before assembly, it is advisable to check the diametric clearance between the rollers and the outer race, and in the case of Nos. 4, 3 and 2 bearings, this must not be less than .0025 inch.

When checking the clearance, the complete bearing should be rested on a smooth plane surface, e.g., a surface plate. The bearings are assembled complete and carefully threaded on to No. 2 crankpin in turn. To thread the bearing on to No. 3 journal, allow the outer race to move backwards

until the rollers protrude approximately one-third of their length from the race. It will then be found that the bearing will pass easily over the next crankweb. In passing from No. 3 journal to No. 3 crankpin, the outer race must be pushed *forward* a similar amount, when it will again be found to pass freely over the web. Care must be taken not to shed the rollers during this operation which is shown at Fig. 865.

Having taken No. 4 bearing to its journal, the split bushes must be put in position. First smear a *little* clean grease on the journal and split bushes before assembly. Every precaution must be taken to ensure the strictest cleanliness of the components. The plain half of the bush is threaded in from the rear side, and passed round opposite the key, raising the bearing with one hand while doing so. This half should be so positioned that, when the keyed half is assembled, the gap between the two is approximately equal at each end; any alteration in the spacing, indicating movement of the plain half of the bush, will then readily be noticeable. To judge the gap, the keyed half is laid on the journal with the keyway in line with the key, and the plain half moved round into correct position. Should any difficulty be experienced in this, before commencing the assembly of the bearings the keyed half of each bush may be pressed home on the journal with the key in position and a line scrived at each end of the bush. These lines are then used as guides for the location of the plain half of the bush on assembly.

The keyed half of the bush is now entered, tapping lightly with a hammer until it is gripped, care being taken that the keyway is in line with the key. The bush is now lightly driven home with a brass drift, taking up each end alternately a small amount until the bush is right home. *The drift must be used on the solid part of the bush only and not on the thin flange.* The bush must be driven in until the flange bears evenly all round the inner race.

If, in fitting, a bush appears to require undue force to drive it in, it should be removed and a bush on the lowest limit of thickness fitted. A guide to the correct tightness of fit is given by the diametric clearance between the rollers and the outer race of the bearing. The fit is correct if this is reduced by about .0005 inch, when the bush is right home. If less, the bush is too slack; if more, too tight. Where a journal is on top limit of diameter, a little selection of both bearing and split bush may be necessary

The procedure in fitting Nos. 3 and 2 bearings is the same as that for No 4, described above, except that in the case of No. 3, it is necessary, during the driving up of the keyed half of the bush, lightly to drive the inner race towards the rear end of the shaft at intervals, in order that it seats on the flange of the plain half of the split bush.

To Fit No. 1 Bearing.—The inner race is heated in oil at 100 degrees Centigrade and placed in position on the shaft. The rollers are assembled in the outer race, dry, and the whole assembled on the inner race. It will be found that if care is taken the outer race can be turned into the vertical position for assembly on the inner race without shedding the rollers. The nut and tabwasher are next put on, taking the nut up hard with a spanner and lead hammer. It should be so arranged that the tab of the washer is

central on one of the flats of the nuts. Since the bearing pulls up on a web of the crankshaft it may be necessary to choose a nut by selection, or, alternatively face down the nut until it will come into the required position. If the nut and locking washer are fitted so that, when the nut is taken up tight with the spanner alone, the tab of the washer lies evenly across one corner of the nut it will be found that the nut will be tightened up to the correct amount when it is hammered up so that the tab falls in the middle of the next flat. This should be used as a guide in fitting.

The setscrews for the split bushes for Nos. 2, 3 and 4 bearings are locked in position by means of split pins. A split pin one inch in length is used, one leg lying straight along the side of the split bush, and the other being bent back to lie along the bush in the opposite direction, the hole in the setscrew lying parallel to the face of the bush.

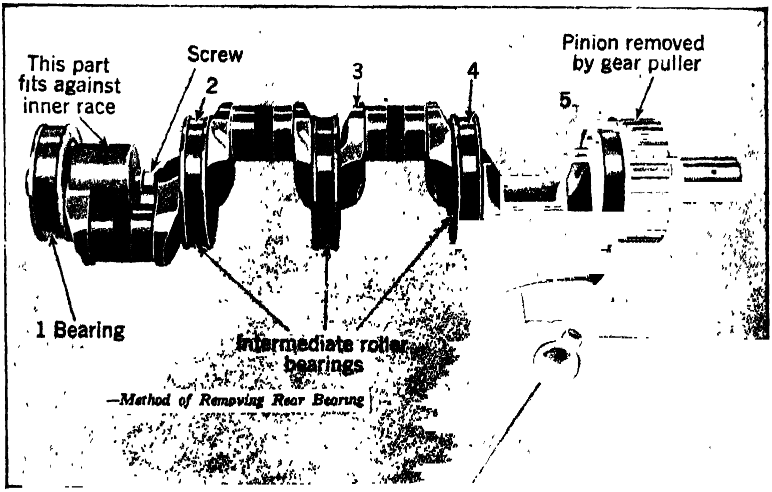


Fig. 866.—Special Puller Used in Removing Number One or Rear Bearing from Napier "Lion" Engine Crankshaft.

Oil Retaining Plugs.—These are lapped into their respective seatings in the crankshaft, using a fairly fine carborundum grinding paste. It is essential that the lapping be carried on until a good seating is obtained, otherwise difficulty will be experienced in making the plugs oil-tight under pressure. Having done this the plugs and bolt are assembled complete with both steel and copper washers, and the hole for the split pin for the nut marked off. Before final assembly the hole for the split pin is drilled and the thread of the bolt tinned, using soft solder. After tinning, a die is run down the thread approximately two turns beyond the split pin hole to remove the surplus tinning. The copper washers must be carefully annealed before assembly. No jointing material is used on the plugs in final assembly. A copper washer is placed next to each plug with the steel washer outside of this. The nuts are taken up reasonably tight, and the oil holes in the crankpins and front plain bearing journal are plugged with soft copper plugs—copper rivets are suitable for this purpose. Test the

oilways and plugs to 100 pounds per square inch pressure, using paraffin with a small proportion of lubricating oil. There should be no leakage at all from the plugs at this pressure. When the plugs are oil-tight the split pins may be put into position and the nuts locked. The crankshaft front end bolt is not lapped to its seatings, but the threads of the bolt must be tinned before assembly. The nut is locked by burring over the protruding end of the bolt into one of the castellations on the nut, after oil testing. Special spanners are provided in the standard tool kit for both the nut and the bolt.

Any plugs which have been removed from a crankshaft must be examined carefully for distortion and cracks. They should be lightly lapped to crankshaft before re-assembly.

Dismantling Roller Bearing Crankshaft.—The rear main bearing should be removed first, followed by Nos. 2, 3 and 4 bearings. The crankshaft pinion is then drawn off the shaft and No. 5 bearing removed. If the crankshaft has run for any considerable length of time it is essential that all oil retaining plugs be removed and oilways cleaned out. In any event, the crankshaft should always be thoroughly cleaned out when the engine is being overhauled. A suitable form of extractor for the crankshaft pinion is supplied in the tool kit.

A tool recommended for use in removing Nos. 1 and 5 bearings is shown in Fig. 866. It may be improvised from a short length of heavy walled tube having a stout plate welded on one end. The internal diameter of the tube should be approximately 3½ inches. A part of the wall is cut away as shown, sufficient to permit of its being passed over the crankweb. The bolt should be made from a hexagonal bar, the end being turned to suit a false center which must be provided to fit in the crankshaft recesses. In use, the cup is placed over the end of the crankweb with its rim bearing on the face of the inner race of the bearing to be removed, the bolt being towards the center of the crankshaft. The thrust of the bolt is taken by the false center which is placed in the recess immediately behind the bolt.

To remove the split bushes from Nos. 2, 3 and 4 bearings it is recommended that two special drifts be made up from steel bar. These are tapered, or reduced at one end, to a rectangular section, and are used as indicated at Fig. 867 which shows the operation clearly. Those for Nos. 2 and 4 bearings being approximately ½ inch by ⅛ inch, and that for No. 3, ½ inch by ¼ inch. This latter conveniently may have a small lip on the lower edge to go under the split bush while driving it out. The drifts should be given a slight bend at a point about two inches from the reduced end, so that the hand will clear the crankshaft in use. The bushes of Nos. 2 and 4 bearings must be driven at each end alternately, but the keyed half of No. 3 bearing bush may be driven out easily over its whole length. Having removed the keyed half of each split bush, the plain half is worked round and removed. The bearings are then threaded off to the rear, the method being similar to that employed in assembly.

Where Nos. 2, 3 and 4 main bearing journals are worn, but not badly so, standard split bushes, slightly small in the bore, may be used to give the necessary tightness of fit. If the wear exceeds .002 inch/.003 inch it is recommended that the journals be ground either to .005 inch or .010 inch

undersize, and special split bushes fitted. No journal should be ground more than .020 inch undersize. If Nos. 1 and 5 main bearing journals are more than .000¾ inch undersize, it is necessary either to grind them down approximately .005 inch below size, and metal deposit them, re-grinding to standard size, or to fit a new race, undersize in the bore.

In all cases where possible crankpins should be lapped to clean up any irregularities of surface rather than re-ground. In the case, however, of badly scored crankpins, where the crankshaft is reasonably true, grinding may be resorted to, but it is pointed out that, in the majority of cases, grinding unnecessarily reduces the life of the shaft. In no case should a

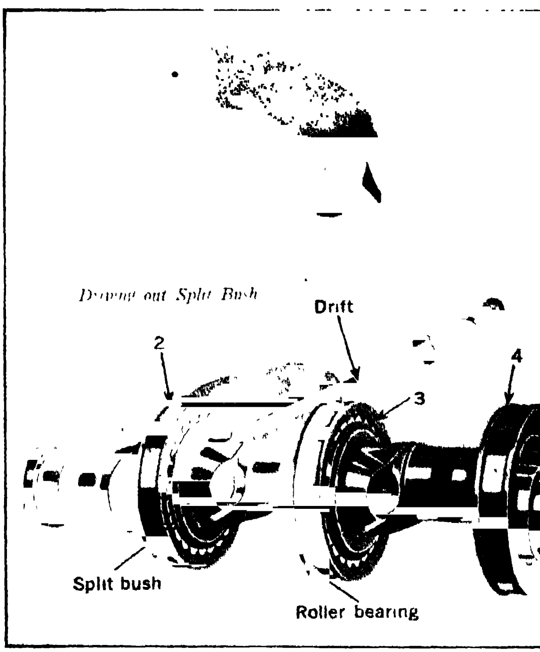


Fig. 867.—Method of Driving Out Split Spacing Bushings from Inner Races of Intermediate Bearings Used in Supporting Napier "Lion" Engine Crankshaft.

crankpin be reduced to more than .020 inch below size. The foregoing remarks apply equally to the front plain bearing journal. If the split bushes show signs of the inner race of the bearing having been creeping, they should be renewed, fitting slightly thicker bushes if necessary.

Applying and Removing Anti-Friction Bearings.—Whenever an anti-friction bearing of either the ball or roller type having hardened raceways is installed or removed certain precautions must be observed to prevent damaging the bearing. The force to move the bearing is applied directly against the member which is a force fit on the shaft. When any form of hub or bearing puller fails to start the member to which it is applied by a direct pull, its action may be accelerated after the screw has been tightened sufficiently to place the parts under a certain initial tension, by a few sharp, well directed hammer blows on the beam or main body of the device.

In all cases where possible, the pressure applied to remove a bearing or part should be exerted directly against the portion that is a tight fit on the shaft or in the housing. In most cases it is the inner member of the bearing that is a force or press fit on the shaft, the outer race member is usually a push fit in the housing and may be more easily removed. If it is necessary to force the bearing off with a series of blows, always use a brass, aluminum or hard babbitt metal bar or drift between the bearing and hammer, or even a piece of hard maple, hemlock or oak. Wood is not as good as metal because chips or splinters may get into the bearing. Even when metal is used great care should be taken to eliminate the possibility of metal particles getting into the bearing, especially when installing.

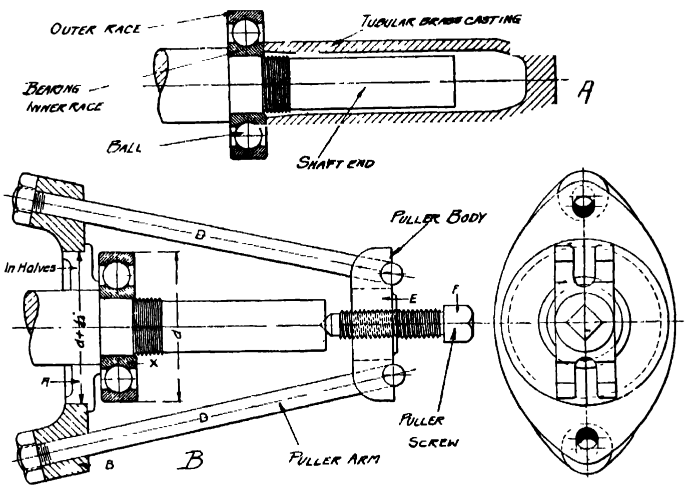


Fig. 867A.—Simple Tools for Ball-Bearing Installation and Removal.

Do not direct all the blows at any one point on bearing as this tends to cramp it and will make it harder to drive off. Distribute them evenly around the entire circumference, always having successive blows at points diametrically opposite. When driving bearings in place, it is always best to use some form of soft metal yoke member or a tubular section piece. With either the yoke or the other tubular form the hammer blows are distributed evenly and the bearing is driven in place without injury to either shaft or bearing components. When a double fork member is used, one end can be made to drive against the inner race member while the other can be spread enough to fit the outer race if desired.

The method of driving an inner race in place shown at Fig. 867 A, is recommended by authorities on ball bearing installation. This is a cast brass tubular member proportioned about as shown. Aluminum or any other relatively soft material will answer in place of the brass. It is possible in many cases to make very satisfactory bearing installing members of standard brass pipe. Most ball bearings have the size number stamped on the side of the inner race. When

installing bearings of the loading groove type always place the unnumbered side on first when driving in place. The tool shown at B, is recommended for removing bearings. The essential point to observe is to exert a steady, uniformly distributed pull on the back side of the inner race in pulling that member off the shaft, instead of against the outer race and the balls. The method of operation is very simple, the inner split ring A is placed back of the inner race X. The split ring is held together by a solid outer ring B placed on its circumference having holes for the straddle bolts D, directly over the joints in ring A. The outer ring B is connected to the cross bar E by the two straddle bolts D. Cross bar E is supported by the set screw F entering the shaft center hole and the bearing is easily withdrawn from the shaft by applying a wrench to the set screw.

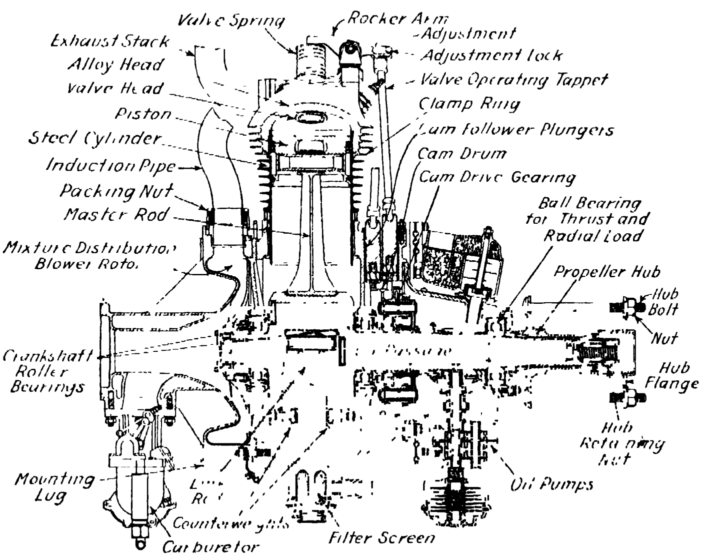


Fig. 867B.—Sectional View of Armstrong-Siddeley Genet Engine Showing Roller Bearing Crankshaft.

In taking up lost motion when any type of adjustable bearing is employed, considerable judgment must be exercised in screwing up on the adjusting member not to get this up too tightly and impose an injurious end pressure on the balls or rollers. An excess pressure that will stress the bearing parts dangerously will not make much difference in the resistance when turned by hand, though when the load or weight must be sustained at high speeds the resistance will be increased materially and bearing endurance reduced in proportion. A safe rule to follow is to take up the wear by screwing in the adjustment nut enough so the "shake" or looseness will be eliminated and yet permit the part supported by the bearing to "spin" for a few revolutions when given an initial impulse. Many inexperienced mechanics commit the error of adjusting bearings of the "take up" type too loosely. This is not desirable, any more than fitting

parts too tightly together is. Always lock any adjustment nut firmly in place when proper adjustment has been secured

In some cases the bearings are shim adjusted. A number of thin washers of sheet brass may be interposed between the bearing cup and the retainer cap. When taking down an assembly of this nature always keep the shims from any bearing box together and tagged for future identification to insure that the adjustment made in the factory will be maintained after re-assembly in the repair shop. If the bearings are loose for any reason, add thin shims about .005-inch thick to the others, until there is no appreciable lost motion and yet no binding between bearing parts.

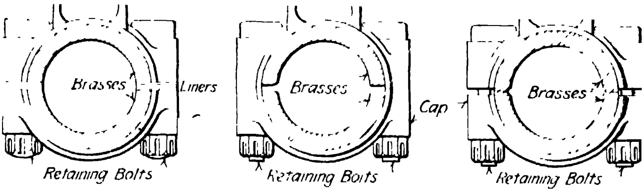


Fig. 868.—Showing Points to Observe When Fitting Connecting Rod Brasses.

Fitting Connecting Rods—In the marine type rod, which is the form generally used in airplane engines, one or two bolts are employed at each side and the cap must be removed entirely before the bearing can be taken off of the crankpin. The tightness of the brasses around the crankpin can never be determined solely by the adjustment of the bolts, as while it is important that these should be drawn up as tightly as possible, the bearing should fit the shaft without undue binding, even if the brasses must be scraped to insure a proper fit. As is true of the main bearings, the horizontally split cap form of connecting rod in some engines has a number of liners or shims interposed between the top and lower portions of the rod end, and these may be reduced in number when necessary to bring the brasses closer together. The general tendency in airplane engines is to eliminate shims in either the main or connecting rod bearings, and when wear is noticed the boxes or liners are removed and new ones supplied though as aviation engines are commercialized, it may be found advisable to use shims just as is done in automobile engine practice. The brasses are held in the connecting rod and cap by brass rivets or screws and are generally attached in the main bearing by small brass machine screws. The form of box generally favored is a brass sand casting rich in copper to secure good heat conductivity which forms a backing for a thin layer of white brass, babbitt or similar anti-friction metal though on bearings that are highly stressed, steel backs are used on various modern engines.

In fitting new brasses to connecting rods there are two conditions to be avoided, these being outlined at Fig. 868 B and C. In the case shown at C the light edges of the bushings are in contact, but the connecting rod and its cap do not meet. When the retaining nuts are tightened the entire strain is taken on the comparatively small area of the edges of the bushings which are not strong enough to withstand the strains existing and which flatten out quickly, permitting the bearing to run loose. In the example outlined at B the edges of the brasses do not touch when the connecting rod cap is drawn in place. This is not good practice, because the brasses may soon become loose in their retaining member. In the case outlined it is necessary to file off the faces of the rod and cap until these meet, and to insure contact of the edges of the brasses as well though the use of other and thicker brasses may entirely cure the trouble. This should be tried before the rod end or cap are filed. About the only time these must be brought closer together is when crankpins have been ground down to smaller size but the best and most mechanical way is to make up special brasses of greater thickness to fill the space. In event of the brasses coming together before the cap and rod make contact, as shown at C, the bearing halves should be reduced at the edges until both the caps and brasses meet against each other or the surfaces of the shims as shown at A.

Sprung Camshaft.—If the camshaft is sprung or twisted it will alter the valve timing to such an extent that the smoothness of operation of the engine will be materially affected. If this condition is suspected the camshaft may be swung on lathe centers and turned to see if it runs out. If so it can be straightened in any of the usual form of shaft-straightening machines. The shaft may be twisted without being sprung. This can only be determined by supporting one end of the shaft in an index head and the other end on a milling machine center. The cams are then checked to see that they are separated by the proper degree of angularity. This process is one that requires a thorough knowledge of the valve timing of the engine in question, and is best done at the factory where the engine was made. The timing gears should also be examined to see if the teeth are worn enough so that considerable back lash or lost motion exists between them. This is especially important where bevel, worm or spiral gears are used. A worn timing gear not only produces noise, but it will cause the time of opening and closing of the engine valves to vary materially.

Precautions in Re-assembling Parts.—When all of the essential components of a powerplant have been carefully looked over and cleaned and all defects eliminated, either by adjustment or replacement of worn portions, the motor should be re-assembled, taking care to have the parts occupy just the same relative positions they did before the motor was dismantled. As each part is added to the assemblage care should be taken to insure adequate lubrication of all new points of bearing by squirting liberal quantities of cylinder oil upon them with a hand oil can or syringe provided for the purpose. In adjusting the crankshaft bearings, tighten them one at a time and revolve the shafts each time one of the bearing caps is set up to insure that the newly adjusted bearing does not have undue friction. All retaining keys and pins must be positively placed and it is good practice to cover

such a part with lubricant before replacing it because it will not only drive in easier, but the part may be removed more easily if necessary at some future time. If not oiled, rust collects around it.

When a piece is held by more than one bolt or screw, especially if it is a casting of brittle material such as cast iron or aluminum, the fastening bolts should be tightened uniformly. If one bolt is tightened more than the rest it is liable to spring the casting enough to break it. Spring washers, check nuts, split pins or other locking means should always be provided, especially on parts which are in motion or subjected to heavy loads.

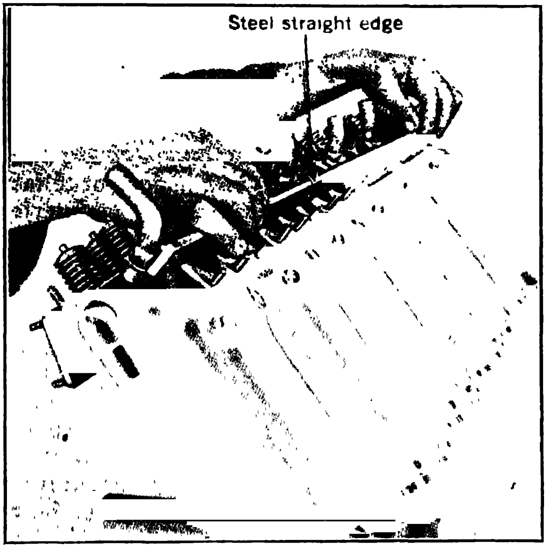


Fig. 869.—Showing Use of Straightedge for Lining Up Individual Cylinders on Engine Base Before Tightening Down Flange Retention Nuts.

Before placing the cylinder over the piston it is imperative that the slots in the piston rings are spaced equidistant and that the piston is copiously oiled before the cylinder is slipped over it. Where the cylinders are individual members and not in block assemblies as in the Packard and Curtiss D12 engines, before the cylinder retaining flange nuts are tightened down, the machined faces on the valve ports against which the manifolds seat should be carefully lined up by using a steel straight-edge as shown at Fig. 869. When re-assembling the inlet and exhaust manifolds it is well to use only perfect packings or gaskets and to avoid the use of those that seem to have hardened up or flattened out too much in service. If it is necessary to use new gaskets it is imperative to employ these at all joints on a manifold, because if old and new gaskets are used together the new ones are apt to keep the manifold from bedding properly upon the used ones. It is well to coat the threads of all bolts and screws subjected to heat, such as cylinder head and exhaust manifold retaining bolts, with a mixture of graphite and oil. Those that enter the water jacket should be covered with white or red lead or pipe thread compound. Gaskets will hold

better if coated with shellac before the manifold or other parts are placed over them. The shellac fills any irregularities in the joint and assists materially in preventing leakage after the joint is made up and the coating has a chance to set.

Before assembling connecting rods on the shaft, it is necessary to fit the bearings by scraping, the same instructions given for restoring the contour of the main bearings applying just as well in this case. It is apparent that if the crankpins are not round no amount of scraping will insure a true bearing. A point to observe is to make sure that the heads of the bolts are imbedded solidly in their proper position, and that they are not raised by any burrs or particles of dirt under the head which will flatten out after the engine has been run for a time and allow the bolts to slack off. Similarly, care should be taken that there is no foreign matter under the brasses and the box in which they seat. To guard against this the bolts should be struck with a hammer several times after they are tightened up, and the connecting rod can be hit sharply several times under the cap with a wooden mallet or lead hammer. It is important to fasten the brasses in place to prevent movement, as lubrication may be interfered with if the bushing turns round and breaks the correct register between the oil hole in the cap and brasses.

Care should be taken in screwing on the retaining nuts to insure that they will remain in place and not slack off. Spring washers should not be used on either connecting rod ends or main bearing nuts, because these sometimes snap in two pieces and leave the nut slack. The best method of locking is to use well-fitting split pins and castellated nuts.

Testing Bearing Parallelism.—It is not possible to give other than general directions regarding the proper degree of tightening for a connecting-rod bearing, but as a guide to correct adjustment it may be said that if the connecting-rod cap is tightened sufficiently so the connecting rod will just about fall over from a vertical position due to the piston weight when the bolts are fully tightened up, the adjustment will be nearly correct. As previously stated, babbitt or white metal bearings can be set up more tightly than bronze, as the metal is softer and any high spots will soon be leveled down with the running of the engine. It is important that care be taken to preserve parallelism of the wristpins and crankshafts while scraping in bearings. This can be determined in two ways. That shown at Fig. 870 A, may be used when the parts are not in the engine assembly and when the connecting-rod bearing is being fitted to a mandrel or arbor the same size as the crankpin. The arbor, which is finished very smooth and of uniform diameter, is placed in two Vee blocks, which in turn are supported by a level surface plate. An adjustable height gauge may be tried, first at one side of the wristpin which is placed at the upper end of the connecting rod, then at the other, and any variation will be easily determined by the degree of tilting of the rod. A dial indicator may be used on the height gauge arm and as these may be obtained calibrated in one-tenth of a thousandth of an inch (.0001 inch) very accurate determinations may be made. This test may be made with the wristpin alone, or if the piston is in place, a straight edge or spirit level may be employed. The spirit level will readily show any inclination while the straight edge is used in connec-

tion with the height gauge as indicated. Of course, the surface plate must be absolutely level when tests are made. The special jig or fixture previously described and shown at Fig. 864 is also valuable in making sure connecting-rod bearings are parallel. Any bent rod should be straightened before it is placed in the engine

When the connecting rods are being fitted with the crankshaft in place in crankcase, and that member secured in the frame, a steel square may be used as it is reasonable to assume that the wristpin, and consequently the piston it carries, should observe a true relation with the top of the engine

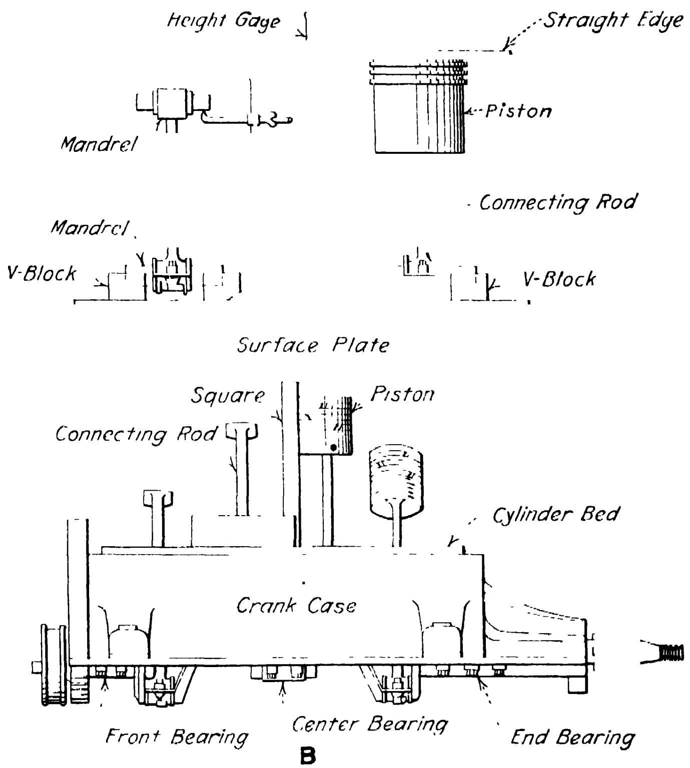


Fig. 870.—Methods of Testing to Insure Parallelism of Crankpins and Wristpins After Refitting.

base. If the piston side is at right angles with the top of the engine base it is reasonable to assume that the wristpin and crankpin are parallel. If the piston is canted to one side or the other, it will indicate that the brasses have been scraped tapering, which would mean considerable heating and undue friction if the piston is installed in the cylinder on account of the pressure against one portion of the cylinder wall. If the degree of canting is not too great, the connecting rods may be sprung very slightly

to straighten up the piston, but this is a makeshift that is not advised. The height gauge method shown above may be used instead of the steel square, if desired, because the top of the crankcase is planed or milled true and should be parallel with the center line of the crankshaft.

Alignment is the secret of success in any automotive engine reconditioning job and that this alignment must be complete with all parts of the engine. Beginning at the cylinder, or crankcase base, we must have absolute squareness of the cylinder bores with this line and perfect parallelism of the crankshaft with the same line. Connecting-rod pins must be parallel with the main bearings. Connecting rods must be straight and square and the piston pins parallel with the crankshaft connecting-rod pins and also square with the sides of the pistons. If there is lack of alignment or of squareness at any of these points, trouble will soon develop and the life of the engine will be appreciably shortened. It is useless to attempt to compensate at one point for error at another. For example, if the connecting-rod pins on the crankshaft are not parallel with the main bearings, the squareness of the connecting rods is useless because the connecting-rod pins on the crankshaft will throw them out of square. If the connecting rod is squared with the crankcase or the cylinder bore, the parallelism of the piston pin and the connecting-rod bearings is thrown out. All of these points must be given the very closest attention if trouble is to be avoided.

Final Inspection of Engine after Overhaul.—It is recommended that in all cases after an engine has been overhauled a careful routine examination of the engine be carried out, and the following schedule is given for guidance by the makers of the Napier-Lion engines though it is not necessarily final or complete and the procedure always depends on the design of the engine:

1. Examine all bolts and nuts for tightness and locking where necessary.

2. Check camshaft gear setscrews for locking and camshaft for oil plugs in the appropriate shafts.

3. Examine valve timing marks on timing gears; magneto timing; timing and locking of gas starter distributor and valve clearances. Examine camshaft casings for presence of foreign matter.

4. See that carburetor base plugs are securely wired up.

5. Check magneto bolts for tightness and see that locking wires are in position.

6. Examine oil suction and drain connection union nuts. See that there is at least $1/16$ inch clearance at back of lock nut from body of union, and that nuts are secure and locked by tabwashers.

7. See that water pump gland and greaser are locked up.

8. See that there is clearance between distributor covers and ignition advance levers on contact breaker cover.

9. See that carburetor stays are bolted securely in position and that carburetor front water pipe is properly supported by clips.

10. Check front oil pipe connections and union nuts for tightness and locking, and $1/16$ inch clearance behind nuts.

11. See that a lockwasher is fitted on front bearing oil pipe union.

12. Check end play in hand turning gear worm shaft. Maximum .016 inch. See that the hand turning throw out tumbler has correct travel, engages

correctly, and does not bind at any point.

13. Examine magneto drive couplings, paying particular attention to the spring driving bars and securing bolts.

14. Check magneto distributors for security of leads and check low-tension cable connections. Check angular movement of magneto controls and contact breaker covers.

15. See that oil relief valve is locked up. In the Series 2 type of valve the adjusting screw must not project more than $^{9}/_{16}$ inch. After test see that the valve is wired up and, preferably, sealed

16. Examine union nuts and locknuts on camshaft oil feed pipes for tightness.

17. See that oil pressure gauge union is securely locked by means of tabwasher.

18. Examine primer pipes for mechanical damage.

19. Check all controls for travel and synchronization, and see that control levers come on to stops. Magnetos should be fully advanced at full throttle opening.

20. Check control rod adjusting screws and locknuts. See that all split pins and locknuts on controls are in position.

21. Check end play in control shafts The play in the rear cross shaft must be kept as low as possible, with 005 inch as maximum. The front cross shaft should have .008 inch/015 inch end play.

22. See that all sparking plugs, and sparking plug hole blanking plugs where fitted, are secure in cylinders and that the copper asbestos washers are sound.

23. Examine H T. leads and carriers. See that they are properly supported, and that all terminal clips are secure.

24. See that plug is fitted to airscrew shaft bore.

25. Test water system to fifteen pounds per square inch water pressure.

26. If engine is to be stored, see that dirt excluders are fitted to all open pipe unions and dust covers to carburetors.

NOTE:—This routine should in all cases be repeated after an engine has completed its final test, prior to installation or storage

Test After Overhaul.—The following is an outline of the procedure adopted at the Works in testing Napier engines. Where a test bed and variable torque brake are available, this procedure may with advantage be adopted as standard if any extensive overhaul of an engine has been carried out.

Test Bench.—The engine bed is of cast iron, fixed on a concrete foundation. A Heenan & Froude brake is used, the engine being coupled to it by a double disc spring steel coupling. A water-cooled exhaust system, leading to a large silencer, is provided. Where considerations of noise make it imperative that a silencing arrangement be provided, the loss of power due to the exhaust system should in all cases be determined by actual experiment.

The fuel flow to each carburetor is measured on a Brown & Barlow Flowmeter, and oil consumption is measured by means of a gauge glass in

the oil tank, a known quantity of oil being poured into the tank and the time for this to be consumed noted. The oil temperature is regulated by a controlled water supply passing through tubes in the oil tank. The cooling water for the engine is taken from a tank, the supply being controlled to give the correct running temperatures. An overflow is provided on the tank and an adequate supply of cold water is available for replenishing the tank if the water becomes overheated.

Independent switches for each magneto are provided and the oil pressure gauge is duplicated. Provision is made for starting the engine by means of the hand starter gear.

Running In.—Run the engine at a speed between 500 r.p.m. and 800 r.p.m., with a light brake load, for at least two hours. The engine is then run up to full throttle, 2,000 r.p.m. and checked for power, balance of flow in carburetors, fuel consumption and ignition. The flow should balance to within $\pm$ 2½ pints per choke per hour. The percentage altitude control is taken and the balance of the carburetors at this point checked. The test is taken by opening the altitude control cock until the engine commences to blow back through the carburetors. This is the maximum control obtainable at ground level with standard jets and should be approximately twenty per cent, the balance being limited to $\pm$ 2½ pints per choke, as in the previous balance check. The maximum range of control may be checked by temporarily substituting larger jets as described in the two hours endurance test details. If necessary the final balance may be obtained by reaming the permanent air leak tube, but this should only be done after a change of diffuser has been tried. The ignition test consists of switching off each magneto alternately, with engine at 2,000 r.p.m. full throttle, allowing one minute to elapse, after cutting out a magneto, before taking a reading. Allow one minute between switching in first magneto and cutting out second magneto. The drop on either magneto should not exceed five per cent for the 5.8 to 1 compression ratio, and six per cent for the 5.0 to 1 compression ratio engines.

Stress is laid upon the importance of accurately calibrating the jets within the limits laid down, i.e., 460 c/c $\pm$ 5 c/c main, and 220/190 c/c $\pm$ 5 c/c pilot, series parallel type jets, or in the case of series type jets, 660 c/c $\pm$ 5 c/c main and 220/190 c/c $\pm$ 5 c/c pilot, and also of checking the flow by removing the diffuser base plugs. The minimum flow for the single carburetor should be 95 pints per hour and for the double carburetor 205 pints per hour with a head of eighteen inches of petrol.

Two Hours Test.—(1) Run the engine at 9/10th rated power, i.e., 405 brake horsepower at 2,000 r.p.m., for 115 minutes. (Both the 5.0 to 1 and 5.8 to 1 compression ratio engines are run at 405 brake horsepower for 9/10th power.) During this time:

(a) Maintain oil pressure at 55 to 60 pounds per square inch at 60 degrees Centigrade.

(b) Maintain oil and water temperatures within the limits:
  Oil: 50 degrees to 60 degrees Centigrade at engine inlet.
  Water: 70 degrees to 80 degrees Centigrade at engine outlet.

(c) Take fuel and oil consumptions.
  These should lie within the limits:
  Fuel: 25½ to 27½ gallons per hour for 5.8 to 1 compression.

28 to 30 gallons per hour for 5.0 to 1 compression.
Oil: (1) With deep chamfer scraper rings: 3½ to 9 pints per hour.
(2) With old type scraper rings or oversize cylinders: six to twelve pints per hour.

(2) At the end of 115 minutes open to full throttle for five minutes, at 2,000 r.p.m. and during this time:

(a) Take brake load and fuel consumption.
Fuel limits:
5.8 to 1 compression: 29 to 33 gallons per hour.
5.0 to 1 compression: 29 to 33 gallons per hour.

(b) Check altitude control and balance.
A reduction of fuel consumption, as shown on the flowmeter, of approximately twenty per cent should be obtainable before serious blowing back through the carburetors occurs, with standard jets. For the test of maximum control special large jets, calibrated to 850 c/c, are fitted temporarily, the limits of control then being 35 per cent to 37 per cent.

(c) Check magneto drop as previously described, taking a mean of three consecutive readings. Average figures for this are:
(1) Running on inlet magneto only:
5.8 to 1 compression: 80 r.p m.
5.0 to 1 compression: 100 r.p.m.
(2) Running on exhaust magneto only:
5.8 to 1 compression: 45 r.p m.
5.0 to 1 compression: 65 r.p m.

(3) Carry out acceleration test. The engine must open up to normal speed from slow running in five seconds without excessive "popping" or rough running.

(4) Take power curve. Readings of airscrew shaft speed and brake load are taken at steps of 100 r.p.m , at full throttle, from 2,200 r.p.m. to 1,600 r.p.m. and up again, reducing speed by the brake.

(5) Slow running test. The brake is left as set for running at 2,000 r.p.m , $\frac{9}{10}$th rated power, and the throttle closed to give the slowest steady running. This should be at a speed not exceeding 450 crankshaft r.p.m.

On completion of the two-hour test, the engine is stripped and an examination of all components carried out. If the replacement of any moving part is necessary a re-test of one hour is given. If a new major component or white metal big end bearing is fitted, a two-hour re-test is generally given. The procedure is the same as that for the first two-hour test, discretion being used as to the time of running in. After re-test, only the new component need be examined.

In the case of an overhauled engine which has had no major components replaced, a duration test of one hour is sufficient.

On rebuilding the engine after first test, the half-hour final test is carried out.

Half-Hour Test.—(1) After warming through, run the engine at $\frac{9}{10}$th power, 2,000 r.p.m. for 25 minutes, taking corresponding readings and tests to those of the two-hour test.

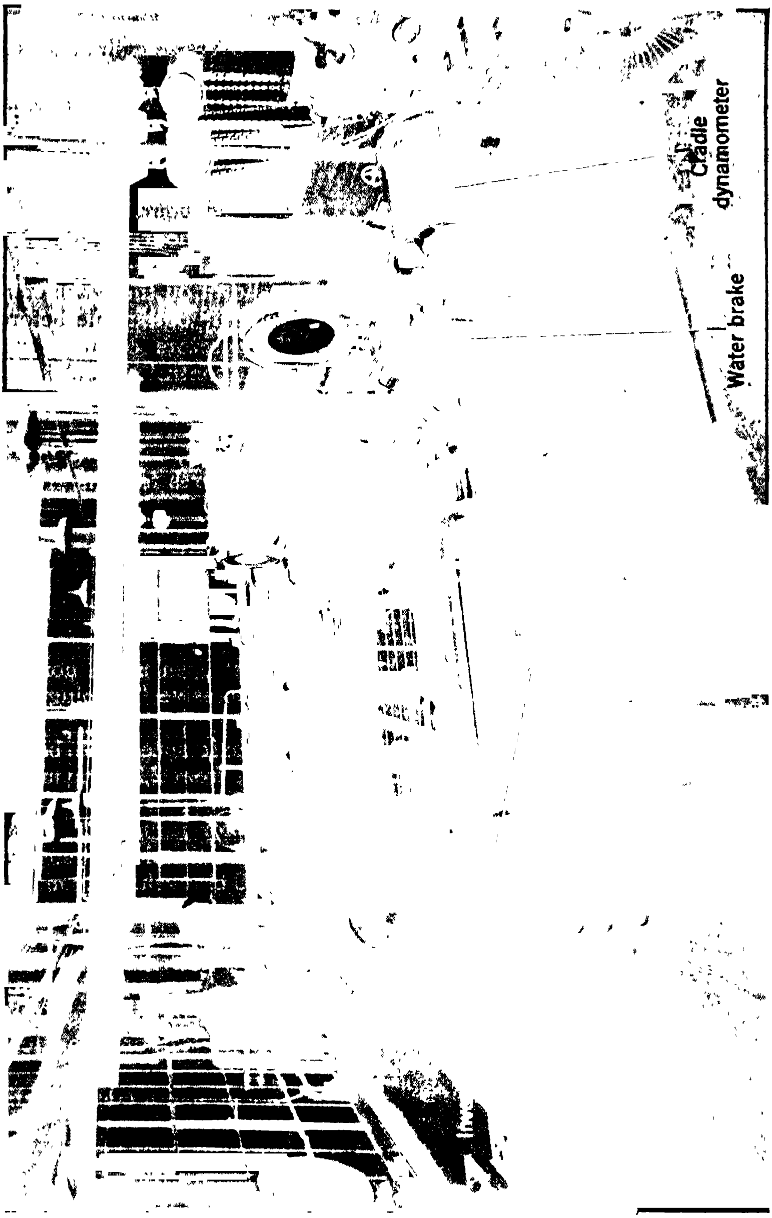


Fig. 871.—The Dynamometer Room of the Aeronautic Engine Division of the Packard Motor Car Company is Typical of Modern Motor Test Rooms. The Power of the Large Engines is absorbed by a Combination of Water Brake and Electric Cradle Dynamometer.

(2) Run at full throttle, 2,000 r.p.m. for five minutes, taking the same readings as in the last five minutes of the two-hour test. Where the sparking plugs are to be delivered with the engine, it is advisable to remove them after this test and examine them, resetting gaps where necessary. A further five minutes run is then given, full throttle power and ignition being checked.

Where facilities for carrying out these tests on a variable torque brake are not available, the routine given must be interpreted, and modified, to suit existing conditions, but **it should in all cases be followed as closely as circumstances permit.**

Where an airscrew is to be used for the tests, it is recommended that a special airscrew, calibrated to absorb 405 brake horsepower at 2,000 r.p.m. be used. A curve giving power at speeds up to 2,200 r.p m. should be prepared for the airscrew, in order that full throttle power may be checked.

Maintenance of Engine in Stores.—When an engine is to be held in stores for any appreciable length of time, it is essential, in order to minimize the risk of corrosion that the following procedure be followed:

It is very desirable that before sending an engine into stores, all trace of castor oil be removed and a mineral oil **free from mineral acid** circulated in the engine instead. Where an electro-motor and stand are available for turning the engine, this may be done as follows:

1. If done immediately after test, **it is important that the engine first of all be allowed to cool.** It is then put on the stand and the motor coupled up. As much oil as possible is drained away from the sump and the drain cocks closed again.

2. Remove breather cap and baffle and pour about four gallons of suitable mineral oil into the engine. Arrange an oil filter so that the top union is coupled to the suction pump delivery elbow and the lower union to the pressure pump suction elbow. Remove the plug from the base of the filter and arrange a pipe from here to the breather. There is now a complete circuit between the suction and pressure pumps through the filter with an overflow to the front of the engine.

3. Run the engine at 200/400 r.p.m. for fifteen minutes and then drain away as much of the oil as possible. **It is important that the full oil pressure, i.e., 60 pounds per square inch, is reached in this run.** To prevent oil pressure rising too high, the pipe from the strainer must be large enough to get rid of the oil, and so keep the pressure down, or an extra large pipe and connections can be fitted, and a cock fitted to regulate the flow of oil. The camshafts and bearings should be wiped over with a clean water-free cloth and surplus oil removed.

4. Pour one gallon of clean mineral oil into the engine and run for a further fifteen minutes; finally draining away all surplus oil.

Where no motor is available for turning the engine after the test or run is completed, a special run should be given, using mineral oil only, the engine being run slowly and the water and oil temperature being kept as low as possible.

5. The engine must now be allowed to become quite cold. Wash down all camshafts and bearings with gasoline and thoroughly dry. If a heated airblast is available, the drying process should be finished with this.

6. Spray all camshafts with an anti-rusting preparation which leaves a thin protecting film on the treated surface, e g . "Sozol Anti-Rusting Preparation," care being taken that the whole of each cam is covered.

If no such preparation is available, the camshafts must, after cleaning, be well covered with mineral oil.

7. By means of a syringe, squirt about one-half pint of mineral oil into each cylinder through the sparking plug holes. In order to ensure that the oil reaches the cylinder walls more or less uniformly, a nozzle having a closed end should be prepared. Holes of approximately 1/16 inch diameter may then be drilled radially round lower part of the nozzle and a few in the closed end, the oil thus being delivered in the form of a spray instead of as a single jet.

8. Pour one-half pint of oil down the oil chute for the airscrew shaft front roller and thrust bearings.

9. Replace breather baffle and cap, put dust covers over carburetor intakes and on all open pipe unions.

10. Clean and dry all bright external steel work and protect by means of "Sozol" or grease.

11. Replace camshaft covers, but these should be raised about 1/16 inch from the heads by means of suitable wood or metal packing in order to provide adequate ventilation for the camshaft casings. Washers are not desirable as packings, for they may fall, unnoticed, into the cam casing.

The engine is now ready for storage, but must be covered while in stores to protect from dust and dirt.

It is recommended that this procedure, where a turning motor is available, be carried out at intervals not exceeding four weeks. If the motor is not available, the engine must be turned through two or three complete revolutions, at least, at intervals not exceeding one week. Camshafts must be examined occasionally for signs of corrosion, and, if necessary, cleaned and treated as previously described. At monthly intervals a certain amount of fresh oil should be sprayed into each cylinder and also poured over the reduction gear through the breather cap, and into the airscrew thrust housing along the oil chute.

In order to ensure that this important routine is carried out, it is recommended that a record be kept, showing dates of turning, during the time the engine is in stores.

N.B.—When an engine is put into service after a long period of storage and maintenance as just described, there will be a considerable accumulation of oil in the cylinders. This oil should be removed as far as possible through the sparking plug bosses before a start is attempted. Otherwise, the plugs will be "oiled up" rapidly.

Selection of Tolerances and Running Fits. Napier-Lion Engine.—The following table gives the running clearances of the more important components of the engine for use in the fitting of new components. All clearances are measured on diameter unless otherwise stated.

Component	*Clearance New*	*Maximum Clearance Worn*	*Remarks*
Crankshaft:	Ins	Ins	
Crankpin Diameter	001¾ 002¾	004	Crankpin may be ground to maximum of .020" below standard size
Parallelism	—	.001	
Ovality	- -	001	
Front Plain Bearing Journal	000¾ 002¼	004	
Main Bearings Roller Clearance before Assembly .	002½ .003		Minimum roller clearance when completely fitted 001".
Rear Bearing End Play . .	001	004	
Spigot for Auxiliary Drive Shaft	000¼ 001¼	003	Bore of Auxiliary Driveshaft may be ground out 040" oversize
Dogs for Auxiliary Drive Shaft	000¼	008	Rotary movement.
Bowing of Crankshaft at Center Bearing .		005	Shafts bowed slightly more than this may be straightened.
Connecting Rods			
Big End Bore . .	001¾ 002¾	004	The weight tolerance over a set of 4 complete connecting rod assemblies should not exceed 1½ ozs.
End Play	003 010	.015	
Twist Alignment of Bores	005	010	On width of Small End Bush.
Parallel Alignment of Bores	003	006	
Gudgeon Pin Bush Bore . .	002 .003	005	Maximum ovality of Gudgeon Pin and Wristpin .001½".
Wrist Pin Bush Bore	001½ .002½	004	
End Play on Pin	004 006	012	
Cylinder:			
Bore ...	022 025½	040	Cylinders may be ground out 010" oversize on bore.
Maximum Ovality ..	—	.004	
Maximum Taper	-	.004	
Piston:			
Diameter (Skirt) ..	022 025½	.040	Maximum wear on Skirt .005".

Component	*Clearance New*	*Maximum Clearance Worn*	*Remarks*
Ovality (Skirt)		.003	
Weight tolerance per Piston in one line	±¼ oz		Total variation in weight of pistons in an engine must not exceed 2 ozs.
Weight tolerance per set of 4 Pistons in one line over engine	±1 oz		
Piston Ring Vertical Clearance in grooves			
(a) Scraper	.003 .005	.010	
(b) Gas	.008 .010	.015	
Piston Ring Gap			
(a) In Cylinder .	.007	.050	
(b) In Standard Ring Gauge		.025	
Camshaft			
Rear Bearing			
Journal	.001 .002	.004	
End Play	.001 .003	.006	
Front Bearings			
Journal	.001 .002	.004	
Drive Top Bearing.			
Journal	.001½ .002½	.004	
End Play	.002 .003	.006	
Rear End Cover:			
Camshaft, and Pump Drives, Auxy. Driveshaft Bearing Journal	.001 .002	.004	
Magneto Drive	.002 .003	.005	
End Play, Camshaft and Pump Drives	.002 .003	.006	

Component	*Clearance New*	*Maximum Clearance Worn*	*Remarks*
Magneto Drive	003 005	008	
Auxiliary Driveshaft . .	006 008	010	
Gear Tooth Backlash	002 004	008	
Hand Starter Throwout Spring Load	45/55		Throwout to release at this pressure.
Revolution Indicator Gear Bearing Journal	001 .002	004	
End Play	.012 015	025	
Valves Inlet Guide Bore	001 002¾	006	
Exhaust Guide Bore	003 004¾	008	
Valve Springs Free Length Inner . Outer	 3¼	Minimum 3 3⅜	Springs need not be checked for load unless below minimum free length. If below minimum should be checked for load before rejection.
Closed Length Inner	1⅞		
Outer	1⅞		
Closed Load. Inner Outer	33/39 lbs 14/17 lbs.		
Airscrew Shaft: Bearing Roller Clearance Front . . . . . Rear		Maximum 003½ 005	Thrust Bearing to have no perceptible End Play.
Reduction Gear: Backlash	005 010	.020	
Carburetor: Gasoline Level ..			8 mm to 10 mm below top of Guard Tube at 2 lbs. per sq. inch pressure.
Flooding Test			Needle Valve to hold 4 lbs. per sq inch petrol pressure.
Needle Valve Seat			To hold 4 lbs per sq inch air pressure

Component	*Clearance New*	*Maximum Clearance Worn*	*Remarks*
Flow (Minimum)			Single 95 pts per hour. Double: 205 pts per hour.
Air Leak Test			1 lb per sq inch air pressure
Pressure Tests:			
Header . .			50 lbs per sq inch, air.
Cylinder Jackets and Induction Pipe Jackets ..			50 lbs per sq inch, air
Water Pipes			50 lbs per sq inch, air.
Carburetor Jackets			15 lbs per sq inch, water
Complete Water System			15 lbs per sq inch, water.
Cylinder Block, complete . .			50 lbs per sq inch, air
Oil Pipes			150 lbs per sq inch, water
Crankshaft Oilways			100 lbs per sq inch paraffin

QUESTIONS FOR REVIEW

1. Why is it important to mark pieces when dismantling an engine?
2. Outline general dismantling procedure
3. Name principal defects in cylinders
4. What is composition of carbon deposits and how are they removed?
5. How are scored cylinders repaired?
6. Describe method of reconditioning valves
7. Outline method of fitting piston rings
8. How are engine bearings refitted?
9. Outline precautions to follow when removing and installing anti friction bear-
10. What general precautions should be followed in re-assembling engine parts?

CHAPTER XLV

DIRIGIBLE AIRSHIP ENGINES—HIGH-SPEED DIESEL TYPES

Power Requirements of Airships—Characteristics of U. S. Navy Airships—Disposition of Engines in Dirigible Airships—Goodyear Nonrigid Airship Details—Hydrogen as Fuel—Acetylene as Fuel—Value of Water Recovery—Water in Exhaust Gas—Water Recovery Apparatus—Steam Cooling for Airship Engines—Development of the Packard 1551 Shenandoah Model Engine—Details of Packard Dirigible Engine—Graf-Zeppelin Characteristics—Maybach VL2 Engines—Maybach Engines are Reversible—Engines Use Blau Gas—Maybach Mechanical Details—Dirigible Power Transmission—Dirigible Engine Clutch—High Speed Automotive Diesel Engines—Diesel Fuel Supply Important—M. A. N. Fuel Pump—Saurer-Diesel Engine—Improved Air-Fuel Mixture Method—Packard-Dorner Diesel Aircraft Engine—The Dorner Diesel Principle—Junkers Aircraft Diesel Engine.

Power Requirements of Airships.—In comparison to their size and weight, the airship requires much less power than an airplane would, assuming that airplanes or other heavier-than-air craft could be built that would carry the useful load of a dirigible. The reason for this is obvious. Engines of airplanes must have sufficient power to lift them off of the earth's surface, be it land or water, and to permit the airplane to climb at reasonable speeds and take-off promptly, twice the power must be provided as would be necessary to cruise at satisfactory speeds, once the airplane is in the air. The lift in a dirigible airship is obtained by static means in most cases, though at times the engines may contribute some dynamic lift. Figures given out by a German airplane manufacturer for a machine of about 160 feet spread and 150 feet length, equipped with a boat hull to accommodate 100 passengers call for a powerplant equipment of twelve 500 horsepower engines, or a total output of 6,000 horsepower. The cruising speed of such giant airplanes will be greater than that of dirigibles, but the power requirements will be over twice that needed by a dirigible capable of carrying 100 passengers at a speed of 70 to 80 miles per hour. It is doubtful if the cruising speed of giant airplanes will be more than 100 miles per hour because the landing speed always bears a definite relation to the maximum flying speed and the problem of landing very large and heavy airplanes at high speed, even on water is a serious one.

Characteristics of U. S. Navy Airships.—The dimensions, weights and performance characteristics of the U. S. Navy ZR1 (Shenandoah) and the ZR3 (Los Angeles) are shown in the following tables, which show the horsepower required by each of these craft. The figures are taken from a paper by Commander Garland Fulton, C.C., U.S.N., entitled "Some Matters Relating to Large Airships" and read before the Society of Naval Architects and Marine Engineers in November, 1925. It will be seen that the Shenandoah, with a total weight of 129,000 pounds and with a horsepower of 1,500, less than provided on some modern trimotor twenty passenger airplanes, had a maximum air speed of 70 miles per hour. The Los Angeles, with a gross weight of 158,000 pounds, and with but 500 horsepower more, or 2,000 horsepower, was capable of attaining the speed of 65

knots as a maximum. The efficiency of the streamlining of the hull of a dirigible airship can be appreciated when one realizes that the cross sectional area of the Shenandoah was 4,818 square feet while that of the Los Angeles is 6,422 square feet. To attain the speeds mentioned with such moderate horsepower, the resistance must be reduced to a low point. Of course, a large reduction in resistance is due to the elimination or overcoming of gravity by the static lift of the gas in the hull.

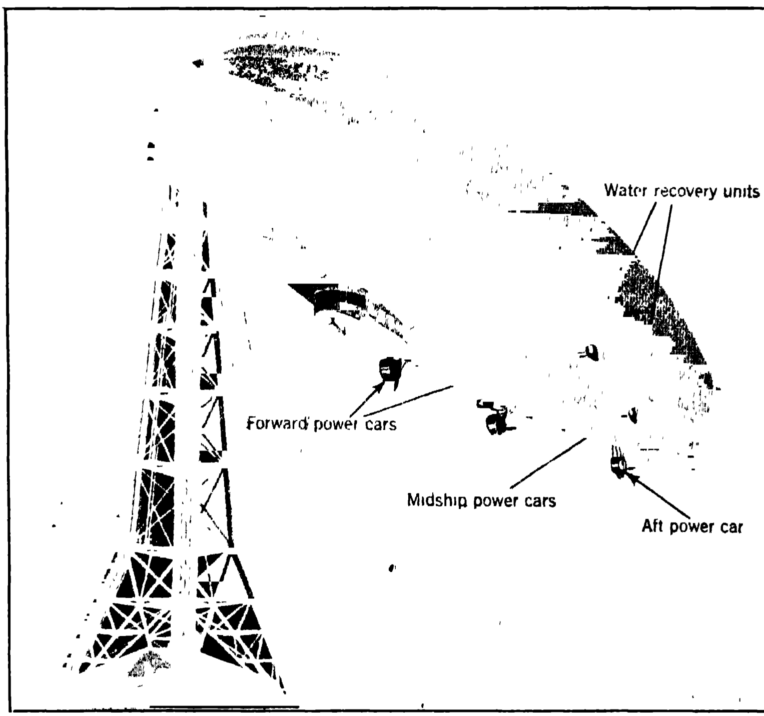


Fig. 872.—The U. S. S. "Los Angeles" Moored to the Mast at Lakehurst, N. J. The Power Cars in Which the Engines are Installed are Clearly Shown. Water Recovery Units May be Seen Above the Side Engine Cars.

The full speed of the Los Angeles is 65 knots, with a fuel consumption of 970 pounds per hour. At two-thirds full power, the speed is 57 knots and the fuel consumption is 590 pounds per hour.

When inflated 95 per cent full with helium lifting 0.064 pound per cubic foot (corresponding to 95 per cent pure gas in dry air at sea level and at a temperature of 50 degrees Fahrenheit), the maximum still-air endurance is as follows:

Speed, knots	Hours	Nautical Miles
65	37	2,368
57	61	[illegible],480
53	70	3,700
44	110	5,200

COMPARATIVE CHARACTERISTICS OF THE U. S. NAVY DIRIGIBLE AIRSHIPS, THE "SHENANDOAH" AND THE "LOS ANGELES"

	Shenandoah	Los Angeles
Air displacement of hull, cubic feet	2,289,861	2,764,461
Volume of gas cells, cubic feet	2,115,174	2,599,110
Length, feet and inches	680 2	658-4
Maximum diameter, feet and inches	78-9	90-8
Total height, feet and inches	93 2	104-5
Engines	5 Packard	5 Maybach
Total horsepower	1,500	2,000
Areas of tail surfaces:		
Horizontal (2), square feet	2,870	2,510
Vertical (2), square feet	2,335	2,510
Areas of rudders:		
Horizontal (2), square feet	446 2	457
Vertical (2), square feet	379 1	400
Area of cross section, square feet	4,818	6,422

COMPARISON OF PRINCIPAL WEIGHTS

95 per cent inflated with helium lifting 064 pound per cubic foot

Items	Shenandoah		Los Angeles	
	Weight, pounds	Per cent gross lift	Weight, pounds	Per cent gross lift
Fixed weights	80,226	62 2	91,030	57 6
Nondisposable weights	20,539	15 9	25,200	16 0
Disposable weights	28,235	21 9	41,770	26.4
Total weights	129,000	100 0	158,000	100.0

The nondisposable weights include the crew, emergency rations, fuel and oil for five hours at cruising speed, and minimum ballast. The disposable weights represent the maximum fuel and oil, over and above the five hours' reserve, which may be carried in the given condition.

Disposition of Engines in Dirigible Airships.—When more than one engine is used for airship propulsion, they are carried in power cars attached to the framework. In the rigid airships, such as the Los Angeles, shown at Fig. 872, the power cars are distributed along the length of the hull, being carried at each side of the bag as shown. Plans for latest forms of airships now under construction in England show the engines carried inside the hull and driving the airscrews, which are distributed just as the power cars are in the present construction, by shafts and gearing. This permits mounting the propellers in streamline housings which will be movable so the axis of rotation can be changed to secure thrust in any direction and facilitate manœuvering the airship.

Power cars are distributed along the hull to divide the static load of the engines and power cars along the frame as well as to distribute the dynamic

load or thrust of the airscrews on various members of the hull framework. The power cars are suspended by streamline struts and braced by steel cables as shown at Fig. 873, which shows the construction and suspension of the Los Angeles power cars, as well as showing the overall dimensions of a typical power car. The engines are Maybach reversible four-cycle,

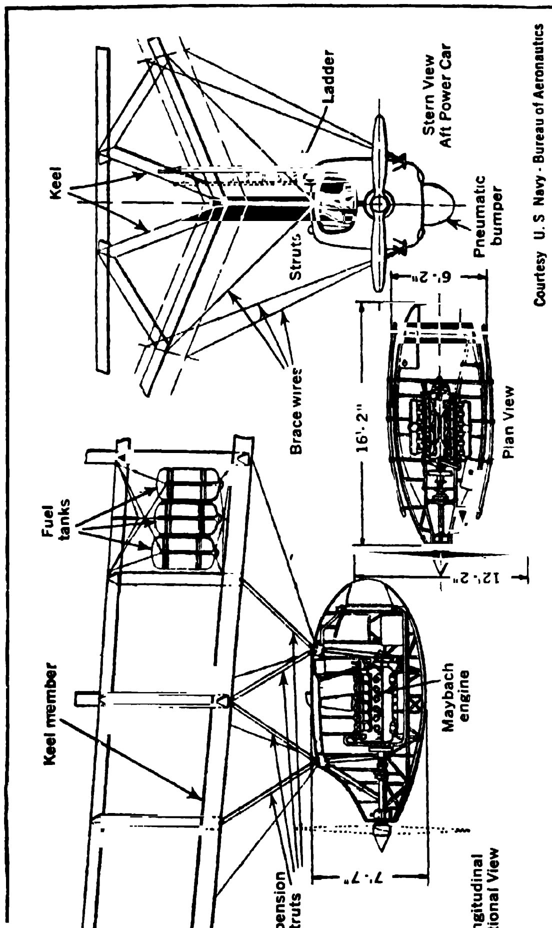


Fig. 873.—The Aft Power Car of the ZR3 or "Los Angeles." The Side Power Cars are Similar Except for Suspension from the Hull. Note Fuel Tanks in Keel.

similar to those used in the Graf-Zeppelin and described in proper sequence. While the sectional views are of the after power car, the side power cars are similar except for suspension from the hull. The reader's attention is directed to the fuel tanks in the keel and the ladder from the keel to the car so the engineer can obtain access to the power car.

In the semi-rigid dirigibles, such as used by the U. S. Army, the power-plants are also carried in power cars, as shown at Fig. 874 and these are suspended from the keel member by streamline struts and braced by cables. The power cars are placed side-by-side, a bridge joining them so the mechanics can go from one power car to the other, and a pair of ladders

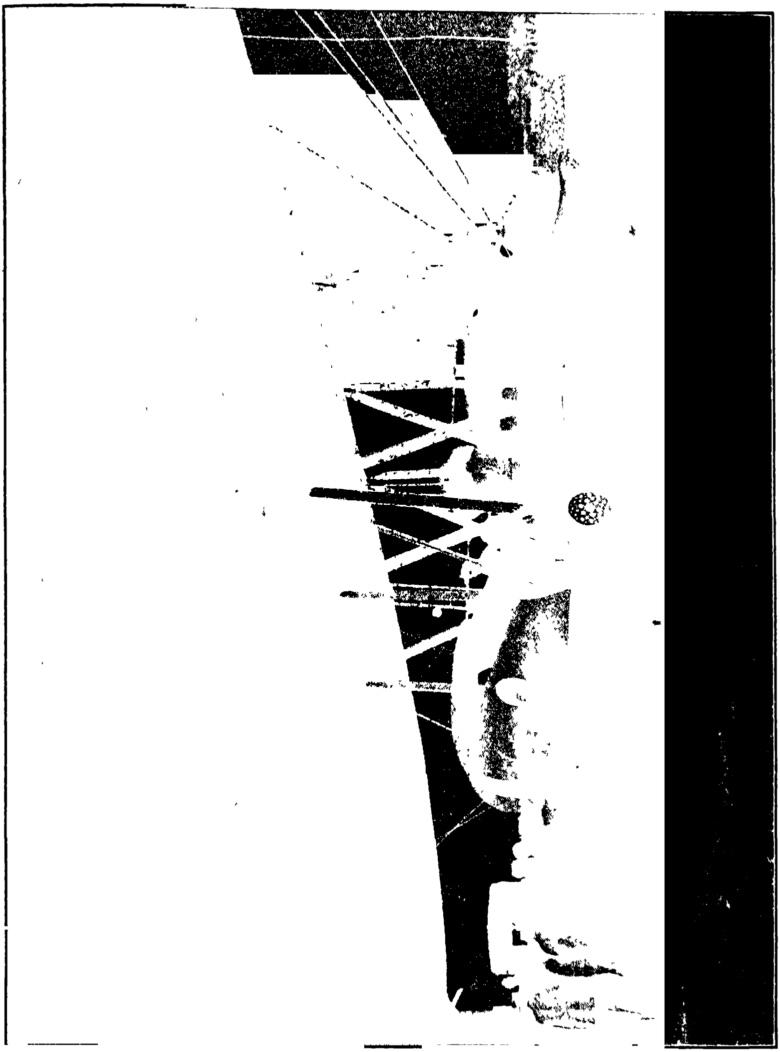


Fig. 874.—U. S. Air Corps Official Photograph Showing the Power Cars of Army Semi-Rigid Dirigible. Note Horizontal Placing of Propellers to Secure Maximum Ground Clearance When Eng are Stopped.

is provided to permit access to the keel member and from thence to the control car. The cars are similar in construction to those used by rigid dirigibles, care being taken to streamline them to reduce their resistance.

Another reason why the engines are carried in power cars in dirigible balloons instead of in the interior is because the fire risk is lessened when

hydrogen is used for the lifting gas and gasoline engines are employed for power. Of course, helium gas greatly reduces risk of fire and gasoline engines may be used. In England, the fire risk is to be reduced in the new series rigid airships by using fuel oil engines of the Diesel type for power so the plans are to mount them inside the framework and reduce the parasitic resistance of the power cars by eliminating them and carrying the airscrews outboard on streamlined frames. Under such conditions, it is believed hydrogen can be used for inflation without undue risk.

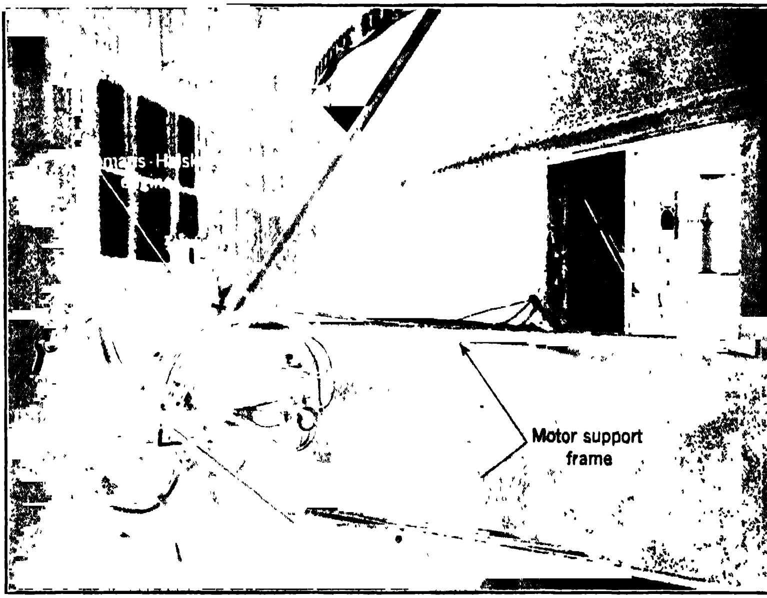


Fig. 875A.—One of the Siemens-Halske Engines Used on the Goodyear Airship "Puritan." Note Installation on Outrigger Tubes.

In the Goodyear-Zeppelin "Puritan" nonrigid airship, the engines are carried by outriggers from the passenger and control car as shown at Fig. 874 and 875. The Siemens-Halske five-cylinder static radial engines are carried by simple tubular outriggers and are provided with a Heywood air starter. One engine is carried each side of the cabin. The large stack shown projecting into the propeller slipstream aft of the engine is one of two that are used to direct a part of the air blast up into the ballonet or air bag used to compensate for variations of gas pressure in the gas bag and keep it properly distended. While the engine accessories are shown exposed in the photographs of the powerplant, they are covered in by a streamline aluminum cowling when the airship is in use. As will be seen by referring to Fig. 875 the fuel and air lines, electric wires and tachometer cable are attached to one of the horizontal bracing struts, but are fully protected when the airship is in service by a cowling that joins the streamline cover of the accessories as shown at Fig. 876. This view also shows the large door giving access to the cabin, which will hold four people.

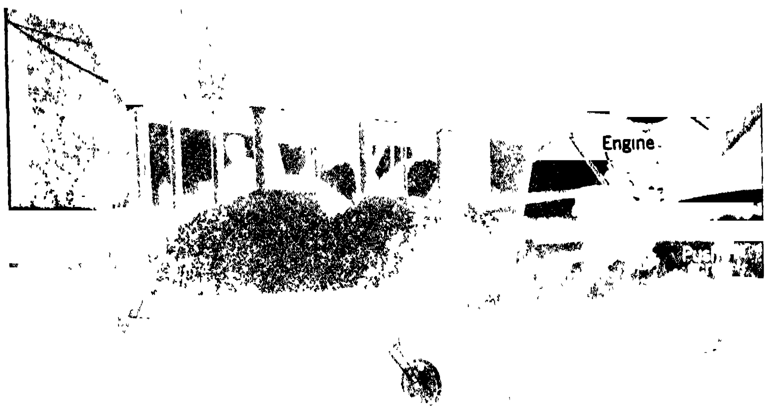


Fig. 875B.—Side View of the Passenger and Control Car of the Goodyear Airship "Puritan" Showing Method of Engine Installation. One Engine is Used on Each Side of the Cabin. Note Air Scoop Placed in Propeller Slipstream for Ballonet Inflation.

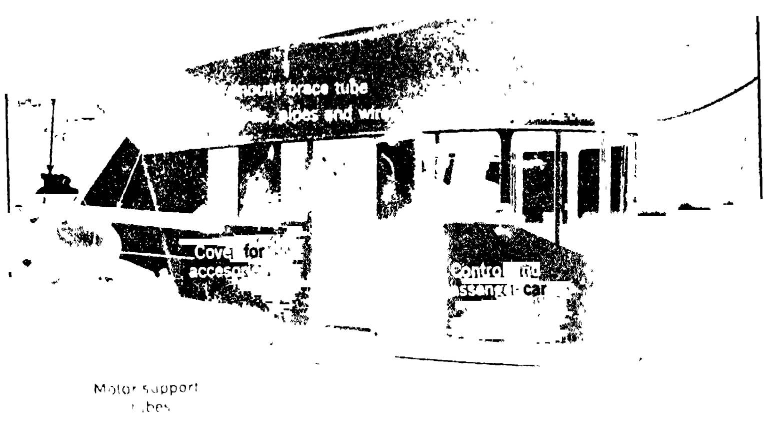


Fig. 876.—View of Right Side of Cars of the "Puritan" Airship. Note Streamline Cowling Over Accessory End of Engine and Covering of All Piping, Wiring, Etc., Leading from Engine to Car.

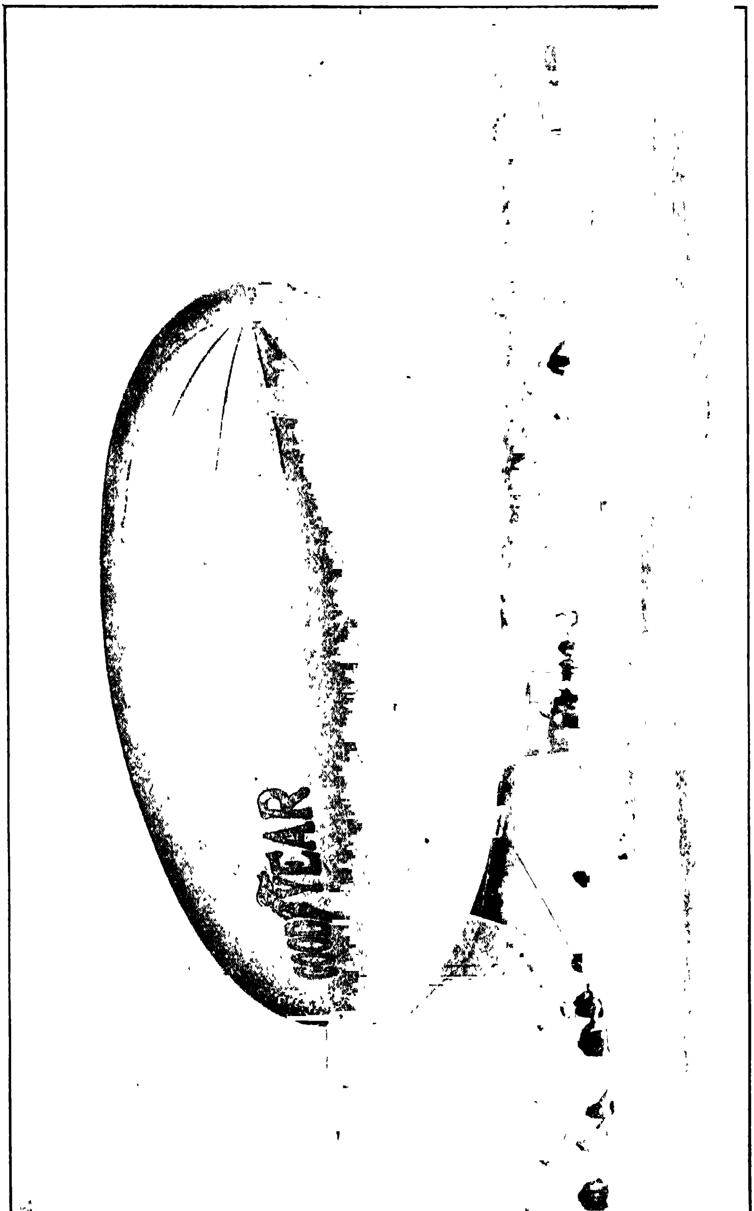


Fig. 877.—The Goodyear Airship "Puritan" Showing General Construction and Location of Power and Control Car Relative to Hull.

Goodyear Nonrigid Airship.—The famous little Goodyear airship, the "Puritan," was put into service during the summer of 1928. The "Puritan," which is shown at Fig. 877, has already been flown several hundred hours, has made three trips to Canada, a number of short flights to various cities in the middle west and to cities on the eastern seaboard. The "Puritan" is somewhat larger than the first Goodyear air yacht "Pilgrim," having a wider cruising range, higher speeds, and greater lifting capacity than its predecessor, the initial airship of the type to be built in America. The "Puritan" is 128 feet long, 37 feet in diameter, holds 86,000 cubic feet of helium, and would be able to travel 550 miles with two passengers and a pilot, without refueling.

The latest aeronautic product of Goodyear is the first ship to be constructed by the Goodyear-Zeppelin Corporation organized three years ago. Dr. Karl Arnstein, formerly chief engineer of the German Zeppelin company and now vice-president in charge of engineering for Goodyear-Zeppelin, was in charge of the design and development work on the "Puritan." The ship has been used extensively for experimental purposes, cross-country flying, and the training of students in the Goodyear airship school at Wingfoot Lake near Akron. The ship is powered with two Siemens-Halske air-cooled radial motors of recent design, has a top speed of 58 miles an hour and a cruising speed of 46 miles an hour, with comfortable seating arrangements for four passengers.

Goodyear has built more than 100 nonrigid airships during the past twelve years and has recently started preliminary construction work on two super rigid naval scouting airships of 6,500,000 cubic feet capacity for the U. S. Navy, the largest airships so far undertaken in the world. Two new airships of the same size and type as the "Puritan" are now under way in the aeronautic workshops of Goodyear at Akron and will be ready for flight in the spring of 1929. One of these airships will probably be sent to the California factory of Goodyear for operation on the west coast.

Hydrogen as Fuel.—Mention has been previously made of the use of Blau gas as a fuel for airship engines. Hydrogen gas which is commonly used for inflation of dirigibles has a very high heating value, 60,000 B.t.u. per pound. Hydrogen has been used as fuel, it being burned in the engines to prevent valving the gas and to compensate for the reduced lift as the gasoline is consumed. When employed in this manner hydrogen is burned in combination with gasoline, which enables one to utilize its properties as fuel, whereas, if used alone, hydrogen will detonate and some modification of existing engines would be needed to secure the best effects. In the United States, helium gas is used for dirigible inflation and water recovery apparatus extracts ballast from exhaust gas to maintain equilibrium as the liquid fuel is used by the engines and the airship is lightened. Despite its high heating value, the heat developed by burning gasoline in the cylinder, owing to the amount of air required to support combustion, is very little different from the energy liberated in the form of heat when ordinary gasoline and air mixtures are used. Hydrogen can be used by having supplementary mixing valves attached to the induction manifolds of the engines and certain proportions of that gas can be admitted in connection with smaller quantities of carbureted air from the liquid fuel carburetors. Helium gas cannot be burned in the engines, in fact, its big advantage is

that it is not inflammable. It is much more costly than hydrogen and only lifts 90 per cent as much weight for the same cubical contents. Hydrogen is used in Europe because there is no Helium obtainable from local sources and it has been produced only in small quantities in European laboratories. This gas is extracted from natural gas found only in Texas in commercial quantities.

Other gases have been proposed as fuel for airship engines besides Blau gas, which weighs about the same as air. Coal gas could be used and would operate the engines very well. Its drawback is that it contributes effective lift to the dirigible as it weighs considerable less than air and the airship would be lightened as the coal gas was used up by the engines.

Acetylene as Fuel.—It has long been known that acetylene is a highly detonating fuel, and it has generally been assumed that this made it undesirable for use with automotive engines. Professor Lutz points out that when the mixture of acetylene and air is too lean, there is trouble from backfiring, which is due to the same cause as backfiring through the carburetor with gasoline, such lean mixtures being very slow-burning. When the mixture is too rich there is trouble from detonation. The theoretically correct mixture which gives complete combustion of the acetylene without excess of air is 11.9 volumes of air to one of acetylene. However, in order to prevent trouble from detonation it is necessary to work with much leaner mixtures, so that there is at all times a considerable excess of air. According to Haber the limiting range of useable mixtures is nineteen volumes of air to one of acetylene to 32 volumes of air to one of acetylene. If water is injected into the cylinders the mixture can be further enriched up to the theoretical proportion of 11.9 volumes of air to one of acetylene.

Any ordinary automotive engine can be operated on acetylene without material changes, and the only objectionable feature is that the maximum output is somewhat reduced, which is a disadvantage of considerable moment in connection with airship engines. There is not the least difficulty in starting the engine; it runs as regularly as clockwork, responds quickly to wide variations in demand, and operates with very clean combustion. All of these good properties were verified in long trials, during which the best operating conditions were ascertained. All apprehension with respect to danger of explosion and the unpleasant odor of the motor fuel was found to be baseless, as these difficulties can be overcome. When it is considered that in the case of acetylene the operating costs are added to by interest, depreciation and maintenance charges on a special generator, the conclusion cannot be avoided that acetylene cannot possibly compete with gasoline under present conditions.

Value of Water Recovery.—Mr. H. F. Parker, while assistant physicist at the Naval Academy Factory, Philadelphia, worked out a system of water recovery from exhaust gas that materially reduces the cost of operation of dirigibles inflated with either hydrogen or the more costly helium, the cost of which has been estimated at figures ranging from twenty cents per cubic foot to five cents per cubic foot. The former is probably none too high, the latter figure is undoubtedly too optimistic for serious consideration in discussing commercial applications of airships. Mr. Parker also covers this

subject in an interesting manner as follows:

"When starting on a flight, an airship is in approximate equilibrium; that is, the lift exerted by the gas within its gas cells approximately equals the total weight of the craft, including the dead-weight of the ship's structure, the ballast, the crew, the useful load and the fuel. As the flight proceeds, this weight becomes gradually less, owing to the consumption of fuel, and the ship becomes light. If no steps were taken to correct it, the first effect would be that the ship would rise, and this would be accompanied by an expansion of the gas within the cells. These cells are normally only partly full but, with increase in altitude, a point is reached where the confined gas expands until it completely fills them. This is known as the 'pressure height.' Any further expansion would cause increased pressure, which is avoided by providing automatic valves that permit the escape of gas under slight excess pressure. Therefore, with the burning of fuel the ship would rise to her pressure height and gas would gradually escape through the automatic valves. Actually, the ship would be kept at whatever height it was desired to fly her by using the elevators to keep her nose pointed downward, thus balancing the excess lift by negative 'dynamic lift,' due to the air pressure on the top of her hull that tends to force her down.

"On short flights, this expedient is satisfactory; and it is even possible to land a ship considerably light by driving her down in this fashion until the landing party has her in hand. Consequently, on ships making short flights only, this lightness is not a matter of much concern; but, on long flights, conditions are very different. It rapidly becomes impossible to maintain equilibrium by the use of the elevators, and lifting gas has to be valved. With hydrogen, this is not serious, for the gas is cheap and can be replaced when the ship returns to her base. This procedure, however, cannot be adopted with helium because not enough of the gas is available. Even if enough were available, the cost of operating with it on long flights without special measures to conserve it would be excessive. On the Shenandoah, operating at cruising speed, with five engines at 1,200 r.p.m., this cost would be $1,000 per hour assuming that the helium cost thirteen cents per cubic foot. This is a very conservative figure at present as it represents merely the cost of producing the gas plus an allowance for transporting the heavy cylinders to Lakehurst, N.J., but it neglects all overhead charges. Ultimately, it may be possible to get the cost down to five cents per cubic foot; but, even at this figure, it will still be necessary to prevent its waste by old methods of operation."

Water in Exhaust Gas.—The point to note is that *for every 100 pounds of gasoline burned, 145 pounds of water is present in the exhaust.* This quantity varies somewhat with weather conditions and also with the composition of the fuel. For gasoline, 135 pounds can be set as the minimum and 150 pounds as a fair maximum; but, with other fuels, the amount of water formed may be greatly different. Thus, with benzol, it is only 70 pounds and, with alcohol, 115 pounds. The water exists first as fog, which cannot conveniently be collected. However, as this fog moves along in the supersaturated atmosphere, the particles coalesce to form water-drops so that, at the exit, probably 75 per cent is available as liquid. The remaining fog can be rendered available as water, by mechanical means. So much for

theory. The problem resolves itself into a straightforward cooling proposition which, at first sight, seems not very difficult. The most obvious thing to do appears to be to apply steam-condenser practice, using either a surface or a jet condenser. The conditions, however, differ from those met with in steam condensers in important particulars.

Water Recovery Apparatus.—The apparatus finally evolved by Mr. Parker and his assistants consists of a large number of aluminum tubes fitted into cast-aluminum headers that, in this case, serve to change the direction of the exhaust through approximately 180 degrees every five feet. The exhaust gas is first directed from the exhaust-ports into a manifold of normal construction As the engine is totally enclosed within a car, special means are necessary to cool the manifold, and it is covered with an aluminum casing provided with an intake scoop to direct air through the casing and over the manifold. A cut-out is provided on the manifold, consisting merely of a branch pipe with a plug screwed into its end so that, on the removal of the plug, the engine can be operated while exhausting direct to the atmosphere, and the condenser put out of action. For normal operation, however, the exhaust flows through the manifold proper to a flexible connection to the condenser entrance. This is necessary because the condenser is suspended directly from the hull, and the cars move almost one inch from their stationary position when subjected to the thrust of the propellers. From the condensers the water recovered is pumped to ballast tanks as required and when in excess, any desired amount may be released to trim ship.

Steam Cooling for Airship Engines.—Evaporative cooling (steam cooling) will be used for the engines of the R101, one of the two new British airships, and a description of the system was given at the recent meeting of the British Association for the Advancement of Science by Wing Commander Cave-Brown-Cave. The airship will be fitted with heavy oil engines built by Wm. Beardmore & Co. The engine cylinders will be filled with water, but the heat absorbed by the water will be carried away as the latent heat of a comparatively small weight of steam. The water is circulated through the cylinder jackets and is always at the boiling point. Since in the normal water cooling system the heat is carried away to the radiator in the form of sensible heat a very material saving can be effected in the amount of water which must be carried.

Owing to the fact that the steam conveying the waste heat is so light, it is possible to use some of the most effective parts of the outer cover of the airship for heat dissipation and to make the heat-dissipating surfaces themselves of a form which would be quite impossible if water were used as the heat-dissipating medium. The system was first applied to an experimental unit at the Royal Airship Works, and a very similar application was made to the power unit which is undergoing tests prior to installation on the R101. Various types of aircraft engine have been fitted with this evaporative cooling system and developed full power without modifications in the engine.

Development of the Packard 1551, Shenandoah Model, Engine.—About six years ago the Navy Department started laying down the plans for a giant dirigible which was to represent an important step in advance over all existing types of the Zeppelin rigid airship. The work of developing the

powerplants for this air monster was entrusted to the Packard Motor Car Company and a set of specifications was drawn up which insured the development of an engine far superior to any yet produced in the United States for this class of service. Reliability, durability, economy, and light weight were the characteristics desired in the order given. Extreme light weight was not nearly as important as it might appear on the surface since a slight gain in economy at some expense of weight could easily result in a larger cruising radius, for after all it was one of the principal aims in the design of the dirigible to obtain the greatest possible cruising range, thus enhancing the utility of the airship for naval purposes. The weight of fuel

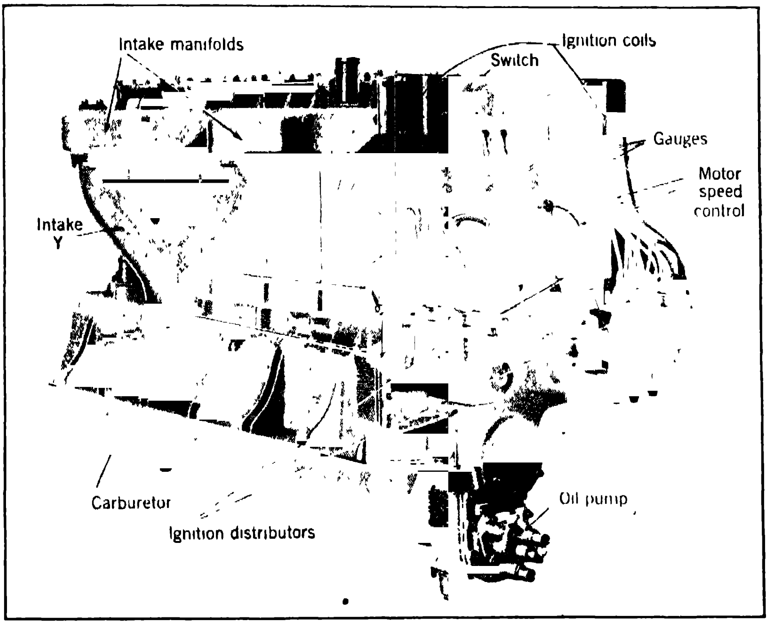


Fig. 878.—Packard Model 1551 Engine Used in the U. S. S. "Shenandoah." Five of These Engines, Aggregating 1,500 Horsepower, Were Used for Power.

to be carried amounted to nearly four times the weight of the engines and every possible effort was expended to obtain the last ounce of power out of the fuel. The net result was that in a 300-hour endurance test of this engine a world's record for economy was made, less than .45 pounds of fuel per brake-horsepower per hour being consumed, which represented a saving of about ten per cent of fuel as compared with the results achieved with other engines over similar tests. This meant that for the maximum cruising range there was a clear saving of 2,000 pounds in fuel, or what represented the weight of two engines

However, the 300-hour endurance test of the Shenandoah engine was not destined to be the only ground test of these engines before the ship made its maiden flight. One of these engines was installed in a fast speed boat, Miss Miami, and for two seasons was subjected to gruelling tests on

Lake St. Clair at times in mountainous seas which tested its reliability and operation at extreme angles. Not a single fault developed and yet still other tests were devised by the Navy officials in their praiseworthy attempt to insure the very finest possible result in the powerplants of the Navy's pride, the Shenandoah. Each of the six engines used in the airship was installed in its power car complete with all its appurtenances, such as gasoline, cooling, lubrication, clutch and reverse gear, engine telegraph, and the numerous other systems necessary to make the power car a complete operating unit.

The power car was then suspended from the roof of one of the giant seaplane hangars at the Philadelphia Navy Yard. Directly in front of the power car a Liberty motor was mounted with its propeller directing the blast over the radiator and forward end of the Shenandoah power car. With this arrangement it was possible to duplicate conditions obtaining in flight, the air blast from the Liberty motor representing a forward speed of about 40 miles per hour. The Shenandoah engines were each given a 24-hour nonstop endurance run and not only the engines but the complete power cars were tested out in this manner. The result was that when the engines were finally installed in the ship they had been proven out by the following series of tests.

(1) Original 50-hour acceptance test.
(2) 300-hour endurance run.
(3) Hundreds of hours of marine service on Lake St. Clair.
(4) 24-hour power car tests at Philadelphia.

A centrifugal type pump is used on the Shenandoah engines and the famous Packard thermostat control is used to regulate the temperature of the water automatically, thus allowing of prompt getting under way and economical running at the most efficient temperature. The oil pumps are located in the sump in the Shenandoah engines and are arranged to be removed easily. An inspection of the engine will show that all accessories have been arranged with a view to readily handling in a power car. As a matter of fact, accessibility was a dominating requirement in the design of the Shenandoah engines. For example, it is possible to remove any one cylinder without disturbing the adjacent cylinders or the manifolds. As a matter of record, a cylinder has been removed from one of these engines, the piston inspected, and the cylinder replaced all in 40 minutes time. On the average marine engine of this size such an operation would require at least several hours labor.

Details of Packard Dirigible Engine.—The Packard dirigible engine, which is shown at Fig. 878, is known as the Model 1A1551 and is rated at a normal output of 337 horsepower at 1,400 r.p.m. There are six cylinders in line having a bore of 6.625 inches and a stroke of 7.5 inches giving a total displacement of 1,551 cubic inches. The compression ratio is 6.5 and the dry weight is 1,060 pounds. The weight per horsepower is 3.15 pounds and the normal brake mean effective pressure is 122.9 pounds per square inch. Individual cylinders, built up of steel forgings, have sheet steel water jackets welded on. A box section type crankcase is parted horizontally at the crankshaft center line. The shaft is an alloy steel forging of the six-throw seven-bearing type and is bored for lightness and to provide passage for the lubricating oil as shown in sectional view at Fig. 879. H section

connecting rods have oil tubes to conduct oil to piston pins and cylinder walls. Aluminum alloy pistons of the die cast trunk type with relieved piston pin bosses are used and are fitted with three rings above and one below the piston pin. Each cylinder head is provided with two intake and

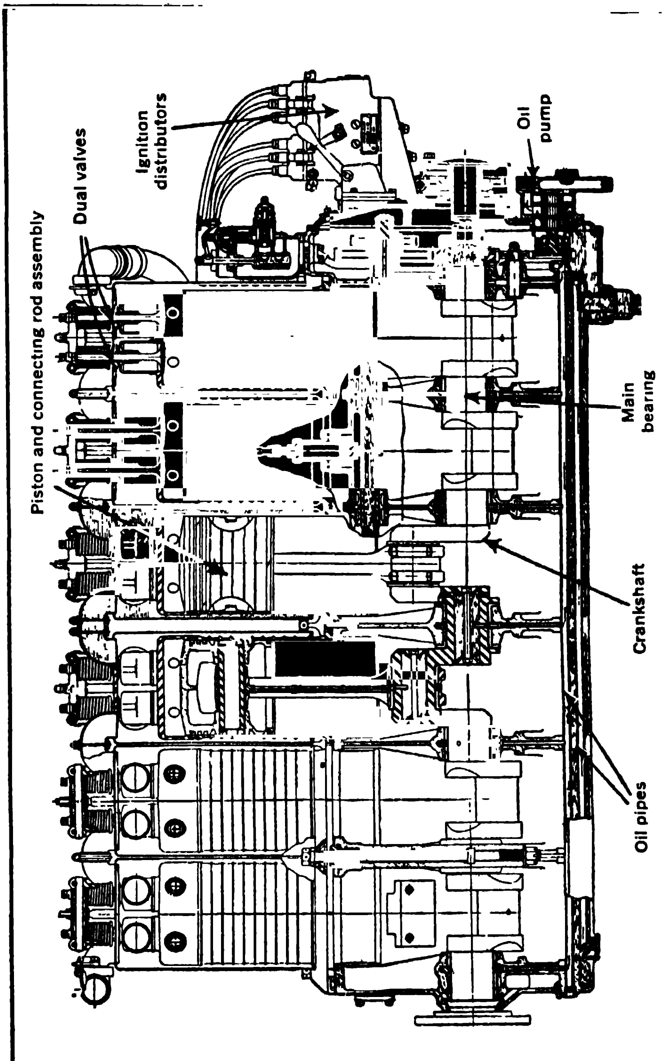


Fig. 879.—Longitudinal Sectional View of the Packard Model 1551 Dirigible Airship Engine Showing Simple and Rugged Construction.

two exhaust valves. Each set of valves is actuated by yoked rocker arms, separate exhaust and intake camshafts being provided, one at each side of the engine. Triple gear oil pumps are used in connection with a dry sump lubrication system. The mixture is provided by a Stromberg NA-ZD5 with back suction mixture control. There are four sparkplugs per cylinder and

ignition is by two Delco six cylinder duplex systems. A twelve volt constant current type generator running at 1½ times crankshaft speed is used. The engine is governed by a centrifugal type governor and holds the engine speed to less than 1,500 r.p.m. and as it works in connection with the oil system, the governor will stop the engine if the oil pressure gets below 25 pounds per square inch. The engine has the following performance:

Maximum brake horsepower at 1,400 r p m	350
Normal rated brake horsepower at 1,400 r.p m	300
Maximum fuel consumption at 1,400 r p.m. normal rated hp	.50 lb./B.hp./hr.
Normal fuel consumption at 1,400 r p m normal rated hp	45 lb /B.hp./hr.
Maximum oil consumption at 1,400 r p m rated hp	03 lb./B.hp /hr.
Normal oil consumption at 1,400 r p m rated hp	02 lb /B hp /hr.
Wt. of engine complete including instrument board and hand starter	1,100 lb.
Weight of water in engine	50 lb.

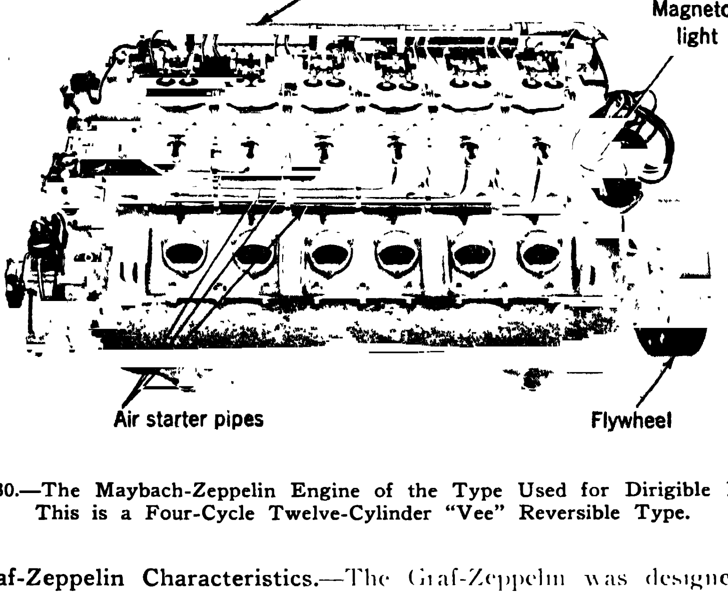


Fig. 880.—The Maybach-Zeppelin Engine of the Type Used for Dirigible Power. This is a Four-Cycle Twelve-Cylinder "Vee" Reversible Type.

Graf-Zeppelin Characteristics.—The Graf-Zeppelin was designed for passenger and mail service on long distance routes. It has a hull of streamline form, free from parallel section. The main frames are 28 sided polygons spaced fifteen meters apart with two auxiliary frames between each main frame. The main frames are wire braced in their own plane and king-post trussed. Both frame and longitudinal girders are of triangular section, but with circular section booms in place of the original Zeppelin open angle-section. The four bottom sides of each polygonal frame are reinforced by a keel framing system. The Graf-Zeppelin has an over-all length of 772 feet, a maximum diameter of hull of 100 feet, a maximum height over-all of 110 feet and a cubic capacity of 3,710,000 cubic feet. It was designed for a gross lift of 107 tons with a pay load of fifteen tons

in addition to a crew of 26 and fuel for 6,200 miles travel at a cruising speed of 68 miles per hour, though its maximum speed is 80 miles per hour.

The Graf-Zeppelin, which completed its trip from Germany to Lakehurst, N. J., on October 15, is powered by five twelve-cylinder, 550-horsepower Maybach-Zeppelin VL2 engines which are housed in individual power cars slung beneath the hull in such a way that the propellers escape one another's backwash. These engines weigh 2,450 pounds each, and the aggregate of 2,750 pounds gives the ship a cruising speed of about 72 miles per hour in still air, a top speed of about 80 miles per hour, and a cruising radius of about 6,100 miles.

Fig. 881.—Three-Quarter View of the Maybach-Zeppelin Dirigible Engine Showing Air Starter Distributor and Engine Control Levers.

Maybach VL2 Engines.—The VL2 engine shown at Figs. 880 to 883 inclusive, is a development of the Maybach-Zeppelin engines in the U. S. Navy's Los Angeles, built in Germany in 1924. That type produced 420 horsepower at sea level and 400 at the altitude of Friedrichshafen, at 1,400 r.p.m. Owing to increased compression, the use of aluminum pistons and carburetor alterations, the VL2 develops 600 horsepower at sea level and 550 at Friedrichshafen, at 1,600 r.p.m. While lightness is the first consideration in an airplane engine, fuel economy and reliability are more important in an airship engine, because on long cruises, such as the Friedrichshafen-New York flight, an airship engine may run as long as 100 hours without stopping. If it is more efficient, the reduction in the amount of fuel that has to be carried will more than offset its greater weight. Whereas most airplane engines requires an overhauling after 300 hours' flying, tests made on the VL2 at Friedrichshafen indicate that it will need minor adjustments only once every 1,000 hours and a major overhauling every 2,000

hours. This longer life is said to be largely attributable to the use of roller bearings. With the exception of the piston pin bushings, all shaft bearings are of the roller type.

Maybach Engines Are Reversible.—Another important quality of an airship engine is direct reversibility. An airship is handled much like a steamship. Its engines must at times go astern so that the ship may moor

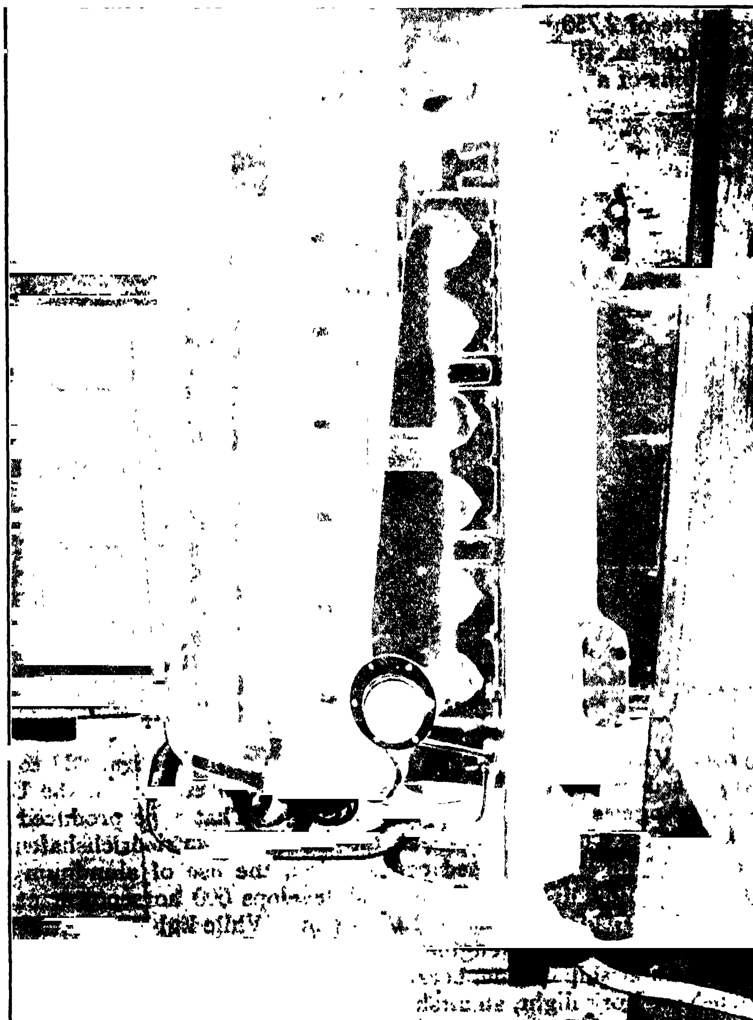


Fig. 882.—Direct Side View of the Maybach-Zeppelin Type VL2 Used for Power on the U. S. S. "Los Angeles" and the Graf-Zeppelin" Dirigible Airships.

or land, as a steamer docks. In previous designs this was accomplished by reversing gears between engine and propeller. These are objectionable, however, because they add to the weight, require longer and heavier power cars, and are the cause of frequent trouble. The VL2 engine is capable of running in either direction. Shifting the camshaft changes the timing of

the 36 overhead valves, and this constitutes the reversing operation. A compressed air starter cranks the engine in either direction.

Perhaps the most significant advance in the Graf-Zeppelin over previous lighter-than-air craft lies in the interchangeable use of liquid and gaseous fuel (gasoline and Blau gas). The use of gaseous fuel in an airship offers great advantages. Carrying gaseous fuel is solely a question of space, weight being a negligible factor; and inasmuch as the head resistance of streamlined airships does not increase in direct proportion to size, an appreciable increase in the cruising radius has been brought about. Furthermore, if the ship had to carry large quantities of liquid fuel, its structure would have to be considerably stronger and heavier.

Ordinarily an airship carries a great deal of water ballast, which can be dropped if buoyancy is lost during flight. The Graf-Zeppelin carries a quantity of gasoline (eight tons) instead. As soon as it becomes necessary to lighten the ship, the engines are switched to burn gasoline.

Engines Could Use Blau Gas.—Blau gas is an industrial gas which has been used in Germany, for railway coach lighting, for harbor buoys, etc. Gas oil (a petroleum fraction) is used as a base in the manufacture of this gas. The oil is subjected to moderately high temperatures in retorts and is thus cracked, and the gas produced is then scrubbed and washed, that is, freed of its tarry material and entrained carbon particles. The gas is then cooled, and when it is to be used for industrial purposes it is compressed to the liquid state and placed in steel bottles. It contains a large proportion of unsaturated hydrocarbons, which makes it particularly suitable for use in internal-combustion engines, as these have pronounced anti-detonating properties and permit of the use of high compression. The specific gravity of Blau gas varies between 1.04 and 1.08. Being slightly heavier than air, the gas flows to the mixers by gravity. A slightly greater weight than air is an advantage also in that the loss in weight with consumption of the gaseous fuel tends to compensate for the loss of buoyancy due to leakage of hydrogen (or helium).

The VL2 was adapted to gaseous fuel by making the throttle valve shafts of the Maybach carburetors hollow. There are four of these carburetors per engine, one to each three cylinders. From the bags containing the Blau gas, pipes lead into the valve shafts. An adjustment valve controls the flow of gas according to the throttle position. Another valve, inserted into the gas feed lines, permits a change from gaseous to liquid fuel or vice versa in a few seconds without stopping the engine.

The specific consumption of liquid fuel at full load is said to average 0.451 pounds per horsepower-hour.

Maybach Mechanical Details.—The crankshaft which is shown at Fig. 884 turns on seven main roller bearings and one combined main and thrust bearing. Lubrication is by spray. One oil pressure pump and two scavenging pumps are provided, one of the latter at each end of the crankcase, so that the drainage may be caught at whatever angle the ship may tilt. The VL2 is a Vee-type engine and water cooled. There are one intake and two exhaust valves per cylinder, these being operated from a common camshaft between the banks of cylinders. Two Robert Bosch magnetos are carried for ignition.

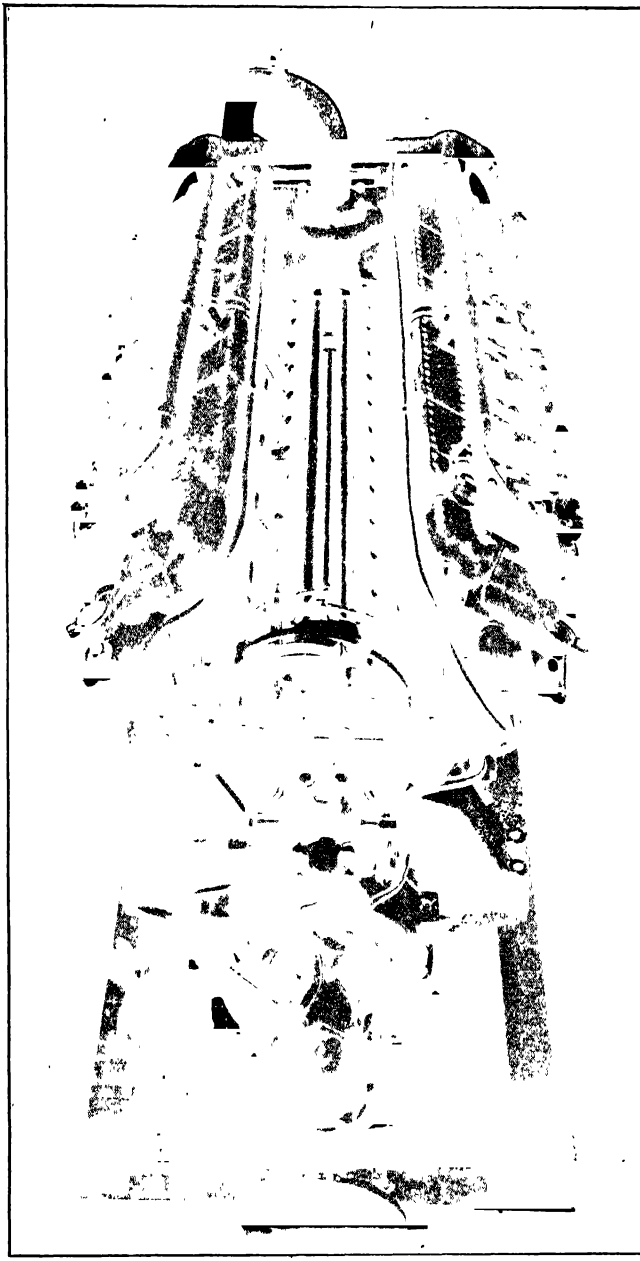


Fig. 883.—Top View of the Maybach-Zeppelin 480 Horsepower Reversible Four-Cycle Engine Suited for Dirigible Airship and Marine Service.

The twelve cylinders are arranged at an angle of 60 degrees, in two rows of six cylinders each. Opposite cylinders are slightly staggered to permit two connecting rods to work on one crankpin side by side. Intake and exhaust valves are provided for each cylinder. These valves are actuated by pushrods and rocker arms from one camshaft. Pistons are cast from a special light metal alloy and they carry four piston rings over the pin. The connecting rods are drop forged in one piece and carry the Maybach patented roller bearing assembly—the most important feature of the motor. This feature insures many thousands of hours of service without replacements. The complete connecting rods are slipped over the crankshaft from either end and secured in place by a pair of split fill pieces and two nuts. This construction is shown at Fig. 885.

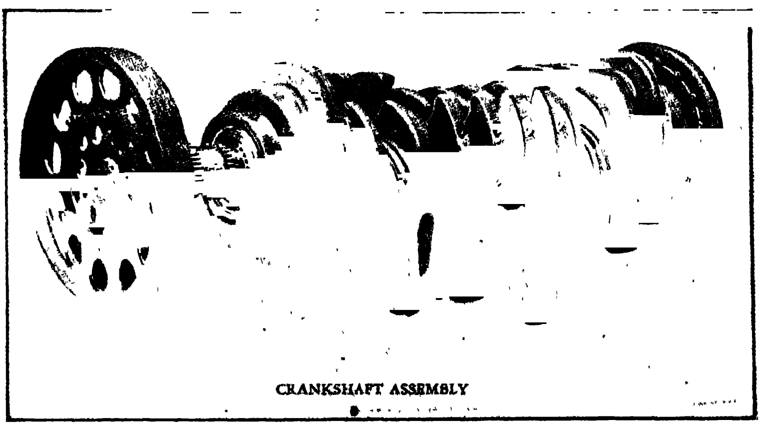


Fig. 884.—The Crankshaft and Connecting Rods of the Maybach VL2 Airship Engine. Note Anti-Friction Bearings Throughout.

The bearing itself consists of an outer race in the connecting rod, eighteen steel rollers held in place by a bronze cage, an inner race, and two split rings which are pressed onto the rollers from the outside by fourteen spring packages. This allows them to roll, at all times, under the influence of the centrifugal force developed by the rotating bearing assembly. Thorough oiling of the connecting-rod bearings is effected by means of oil catchers which take their oil from jets and feed it to the bearings through large openings. (See illustration.)

The crankshaft is a single piece of steel drop forged. It is machined all over, carefully balanced, and supported by seven strong roller bearings in the upper half of the crankcase. Counterweights are strapped to the throws of the crankshaft as shown in the photograph. The camshaft and magneto drive is worked by two gears on the after end of the shaft. These gears also drive the oil pressure pump, the two oil scavenging pumps, and the water circulating pump. The oil pumps are located in the lower part of the crankcase while the water pump is attached to the outside of the case where it is conveniently accessible. The oil pumps have a cleverly arranged double set of dog clutches that operate alternately when the engine is running

either forward or in reverse. These pumps can be removed easily without removing any part of the engine. The greatest weight reducing factor of these motors is in the successful elimination of reverse gears. The reversing of these motors is accomplished by the shifting of the camshaft which brings a different set of cams into operation—thus these engines can operate

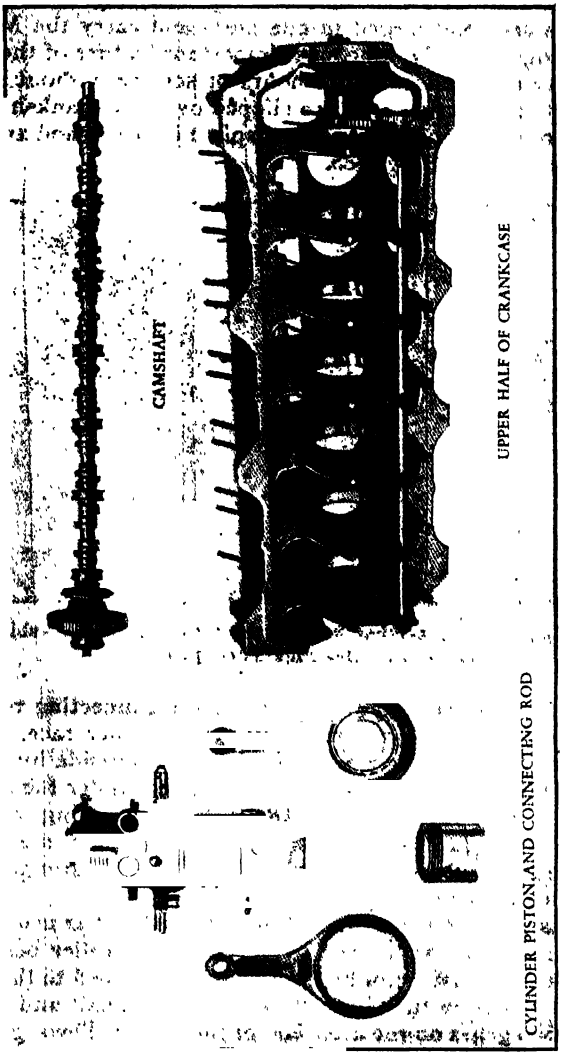


Fig. 88[illegible].—Some Important Structural Parts of the Maybach-Zeppelin Type VL2 Engine as Used in the "Los Angeles" and "Graf-Zeppelin" Dirigible Airships. Note Unusual Construction of Connecting Rod with Anti-Friction Bearings at Big End. The Camshafts Have Two Sets of Cams, One for Forward Motion the Other for Reverse Motion. The Substantial Yet Light Construction of the Crankcase Upper Half is Also Clearly Shown.

in opposite directions with the same speed and power, whereas there is a loss of power through reverse gears that cannot be avoided.

Electrical starting devices are not satisfactory on engines of this size and power. Therefore, an air starting system has been designed and installed. It consists of a distributor with two cams for forward or back-

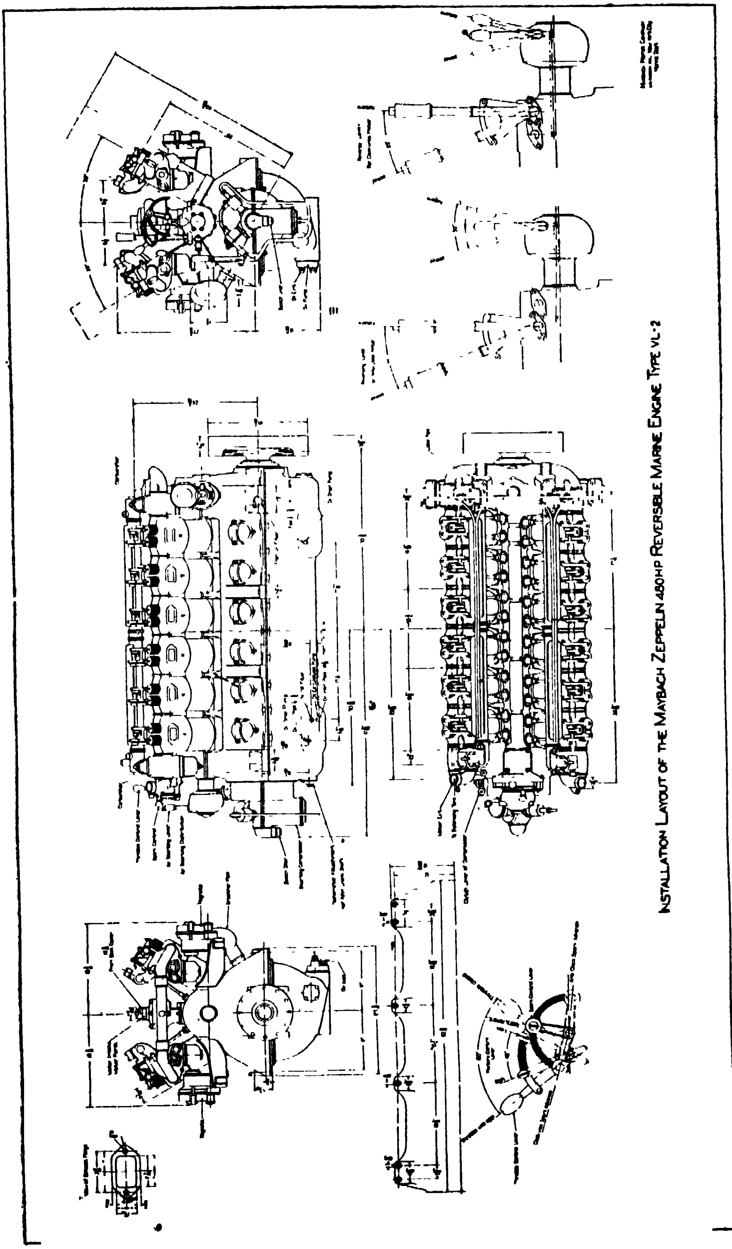


Fig. 886.—Installation Layout of the Maybach-Zeppelin 480 Horsepower Reversible Airship and Marine Engine Type VL2.

ward starting, six airlines, and six automatic self closing air valves on each of the six cylinders on one side of the motor. A two-stage air compressor, attached to the forward end of the motor, restores the air in the air bottles. This compressor is controlled by means of a hand lever clutch. The upper half of the crankcase shown at Fig. 885 shows a very sturdy design in the seven main bearings which carry the crankshaft. The bolts carrying the main bearing caps run up through the light metal alloy case to the top—taking all strain off the casting. All auxiliary machinery like the fresh water circulating pump, magneto leverage for advancing and retarding the spark, reversing, starting, etc., are integral parts of the motor and assembled to the upper half of the crankcase. Manifolds, leading from the breathers of the crankcase to the air intakes of the carburetors, take care of the exhausting of the oil and gas fumes from the crankcase. This is a point of vital importance in the cooling of reciprocating parts and in freeing the engine car of all oil fumes and smell. The installation drawing at Fig. 886 gives the main dimensions of the marine type Maybach-Zeppelin motor but this is practically the same as the VL2 used for the Graf-Zeppelin and other airships

SPECIFICATIONS MAYBACH AIRSHIP MOTOR

Weight of complete motor, 2200 lb, 480 horsepower, 2055 cubic inches cylinder displacement
Number of cylinders, 12
Bore, 5½ inches
Stroke, 7⅛ inches
Horsepower at 1450 R P M, 480
Fuel consumption from 0 45 to 0 51 lb per horsepower an hour
Weight per horsepower, 4 57 pounds
40 horsepower per cylinder
2 Robert Bosch 12 magnetos operating in either direction
2 plugs per cylinder, Robert Bosh type Rde
5½ gallons of fresh water in cooling system
Thermal efficiency, 36%
1 intake valve per cylinder, 2 65 inches diameter, 0 535 inch stroke
2 exhaust valves per cylinder, 1 923 inches diameter, 0 25 stroke
4 patent Maybach adjustable fireproof carburetors

Dirigible Power Transmission.—Sometimes in dirigible balloon practice it is desirable to mount two engines in one power car and to have mechanism that will permit of driving one propeller with either or both engines. With a transmission system of this nature, which usually includes an independent clutch for each engine, in event of failure of one powerplant the propeller may be driven by the other. Sometimes using two engines is an operating advantage as under favorable conditions, part of the powerplant may be shut-off and disconnected from the propeller with an attendant fuel saving. The use of a clutch also permits of repairs being made on one unit of the powerplant.

The transmission of the U. S. Army Type RS1 semi-rigid airship shown at Fig. 887 A shows the type of mechanism employed when two engines drive a single propeller. The forward engine drives the gear box by a separate driveshaft which extends along the crankcase of the aft engine as shown. A disengaging clutch is placed between the engine and the drive-

shaft flexible coupling. The aft engine is connected to the gear box through a clutch, coupling and a considerably shorter length of shaft. The gear housing contains reverse gearing for the rear engine and not for the front one because sufficient thrust is obtained for maneuvering in a reverse direction with one engine. This arrangement permits of starting one engine

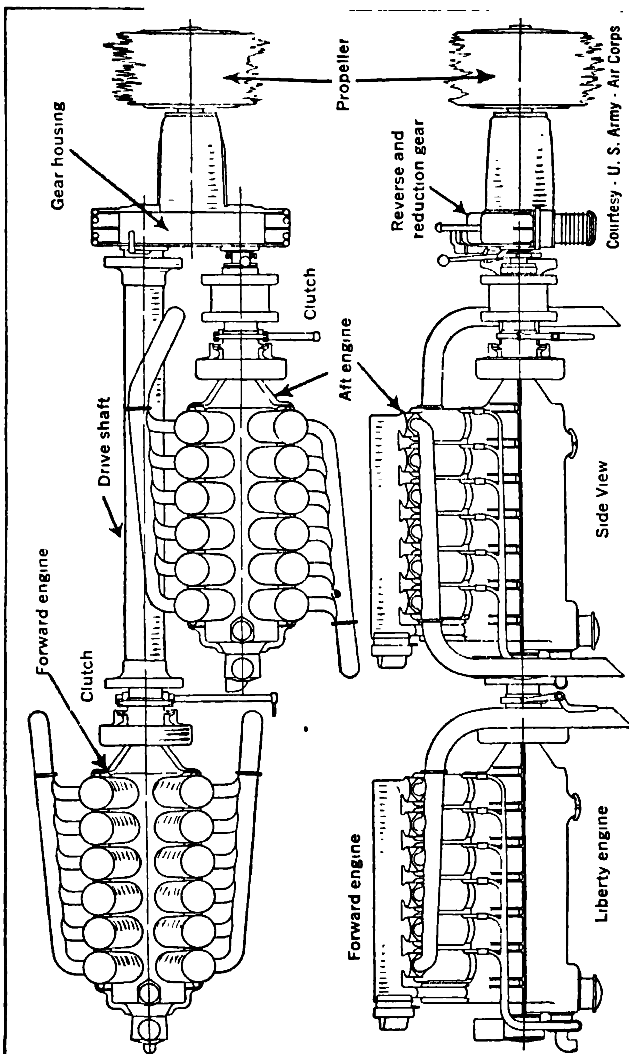


Fig. 887A.—Drawings Showing Construction of Transmission System Built for U. S. Army Semi-Rigid Airship Type RS1. This Permits the Use of Two Engines to Drive One Propeller.

by the other is desired. The ratio of drive is twelve to five, i e., the engine shafts make twelve revolutions to produce five of the propeller. This makes possible the use of a large diameter, slow speed propeller of a form having efficiency characteristics specially adaptable to dirigible balloon propulsion. It is stated that the weight of such a transmission system,

including clutches, drive couplings and driveshaft is about 800 pounds.

Dirigible Engine Clutch.—The clutch used with the engines of the Shenandoah is shown at Fig. 888. This is mounted at the rear ends of the Packard 1551 engines shown at Fig. 877 B and is interposed between the crankcase and the reduction and reverse gearing previously described and illustrated at Fig. 812. The clutch brake interposed between the clutch and gearset is utilized to arrest clutch rotation when gears are shifted or to stop the propellers in a horizontal position to obtain ground clearance, as shown at Fig. 874, which shows the actual power cars of an Army Type Semi-Rigid dirigible. The clutch disc driving member is in the form of a light wheel, this being necessary to insure smooth running of the engine

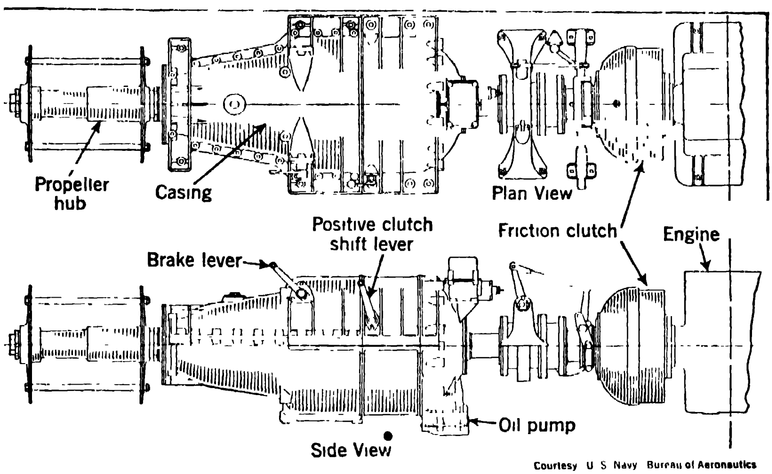


Fig. 887B.—The Reduction Gear and Clutch Assembly Used with Packard 1551 Dirigible Engines on the U. S. S. "Shenandoah."

when the propeller, which normally provides a fly wheel action is declutched from the engine. A series of discs are driven by the flywheel by integral keyways, this flywheel also serving as a clutch casing. The driven discs are mounted on a splined hub member that extends out from the casing and attaches to the driveway flange of the flexible coupling. The clutch discs or plates are pressed together by toggle linkage actuated by a sliding sleeve and the pressure transfer member is threaded into the pressure plate in such a way that it can be adjusted from the outside of the clutch casing to vary the pressure exerted by the toggle links.

High-Speed Automotive Diesel Engines.—In a paper read before the S. A. E., Dr. Wilhelm Riehm, discusses the subject of automotive Diesel engines and while the engine he describes was designed for motor truck use, it is not likely that Diesel engines designed for airships will vary much in principle from those suited for automobiles. There will be a refinement in design to reduce the weight and liberal use of high strength steel alloys will undoubtedly be necessary to obtain the required resistance without too much weight. It follows that, because of the unfavorable properties of heavy oils for use with the explosion method, this fuel should

be utilized by the Diesel method; that is, injection of the fuel into highly heated air, with spontaneous ignition. The lower ignition point promotes spontaneous ignition, in this case, while the long boiling curve, due to the composition of the fuel, is necessary for quiet combustion. The spontaneous ignition of the fuel in the working air, however, requires substantially higher compression than is customary in carburetor engines, and this leads to higher ignition pressures and greater stresses on the working parts.

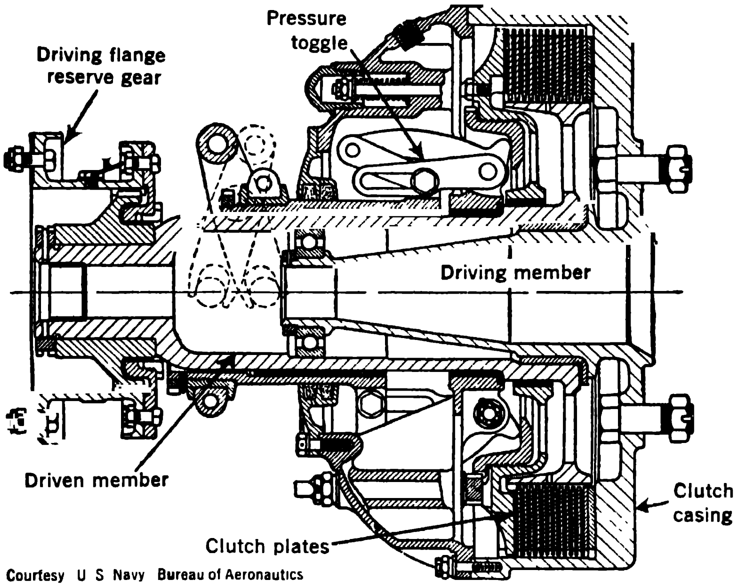


Fig. 888.—The Clutch Mechanism and its Parts Used in the U. S. S. "Shenandoah" Transmission System.

The question may be asked whether these higher stresses are such that, because of the more rugged construction required, the weight of a light engine operated on the Diesel principle would be appreciably higher than that of the carburetor engine. If this question is to be answered first respecting the working parts, this must be done on the basis of the maximum pressures. In the case of carburetor operation, in which the explosion pressure cannot be controlled with the same certainty as in Diesel engines, the maximum pressures have been up to 28 atmospheres or more in recent designs. When using the Diesel principle, a combustion pressure of 42 atmospheres may generally be assumed for high-speed engines.

The diameter of the connecting rod is governed by the maximum cylinder pressure, increasing with the fourth root of the pressure. Hence, raising the pressure 1.5 times increases the diameter of the connecting rod ten per cent and its weight about 21 per cent, pre-supposing a connecting rod of circular cross-section. The dimensions of the crankshaft are based upon the maximum tangential pressure at a crank angle of 30 to 35 degrees, and

the crankshaft must be four to five per cent heavier than in the carburetor engine.

Because of casting and manufacturing considerations, the wall thickness of cylinders, cylinder-heads, pistons and crankcase generally are so heavy that they will not need to be made heavier for the higher ignition pressures. The fuel-injecting device provided instead of the carburetor also can be very light, so that the Diesel engine will weigh only ten to fifteen per cent more than a carburetor engine of the same cylinder displacement. Since, in the vehicle engine, the weight is always related to the attainable power, one must investigate also how the power will compare in the carburetor

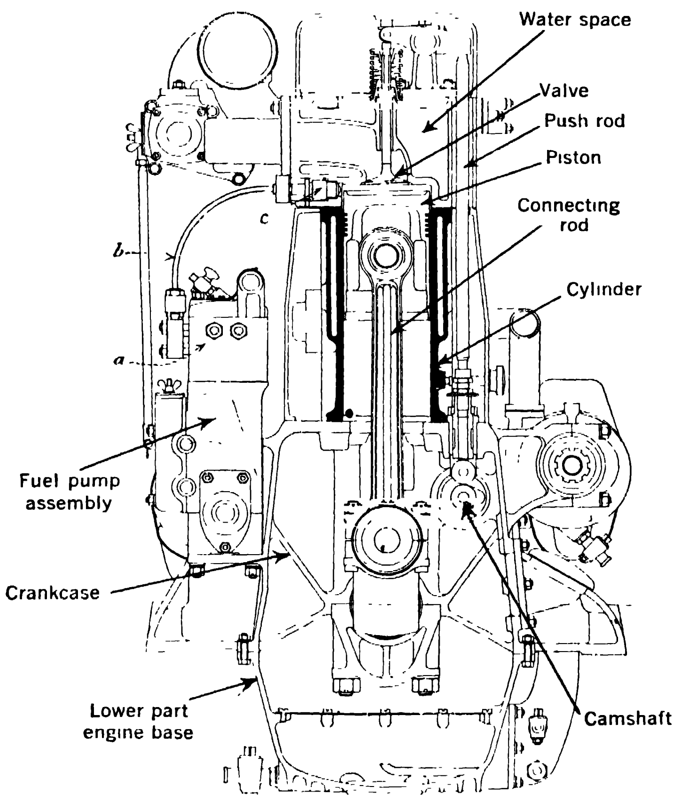


Fig. 889.—Cross Section Showing Construction of M.A.N. Automotive Diesel Oil Engine, Showing Fuel Injection Apparatus. The Fuel Pump (a) Supplies the Fuel Injection Nozzle (c) by Oil Pipe (b).

engine and the Diesel engine for the same cylinder displacement. The power depends on the attainable mean effective pressure and the highest practicable speed. Carburetor engines usually attain mean effective pressures between six and seven kilograms per square centimeter (85 to 100

pounds per square inch). In Diesel engines that have been in satisfactory operation on cars for years, mean effective pressures up to six atmospheres (88.2 pounds per square inch) are obtained normally with good combustion. At lower speeds, mean effective pressures greater than seven atmospheres (102.9 pounds per square inch) can be attained for short periods. On the whole it can be said that the Diesel engine will hardly fall below the average carburetor engine in driving torque though some carburetor engines will show a performance very much above the average.

Whether greater limitations are imposed upon the speed range of the Diesel engines cannot be decided now, but, with the same normal speed, the lowest speed at which the engine will ignite regularly probably will be the same as for the gasoline engine. Also the upper limit of around 2,000 r.p.m., required for auto engines, probably can be reached without difficulty. From this it follows that, with the same cylinder volume, approximately the same power will be given by the Diesel engine as by the carburetor engine and the weight will be from ten to fifteen per cent greater for the Diesel engine.

Diesel Fuel Supply Important.—The main consideration in Diesel engines for various automotive uses is in the method of fuel supply. Air injection, which has been previously described, is not suited for an engine that is to be light in weight because the compressor and air storage introduces considerable extra weight. Diesel engines of the airless injection type are best adapted for automotive work. There are two main systems, one known as the ante-chamber system; the other is the pressure atomization system. Ante-chamber injection has as its main feature a chamber placed ahead of the working chamber into which the fuel is injected and partially burned. In such engines the compression is about 35 atmospheres and combustion pressure 40 atmospheres In the pressure atomization method the fuel is injected directly into the combustion space. The injection device requires very accurate timing and to secure even approximately perfect combustion, a definite and precise relationship must be secured between injection time and the piston travel. Ante-chamber engines must be provided with a spring loaded needle valve controlled by fuel pressure and these valves are delicate in construction and some parts, the needle tip and valve seat in the nozzle are subjected to considerable wear. The pressure-atomizer system is simple because an open nozzle is used and the only moving parts subject to wear are in the fuel pump. The pressure-atomizer engines are easier to start while ante-chamber engines must use ignition cartridges, electric heating coils or other devices to facilitate starting.

In the M.A.N. four-cycle car-engines, which have been used extensively during the last two years for the propulsion of vehicles, the pressure-atomizer system has been given preference. According to conditions, either two opposing nozzles or a single nozzle can be employed. Also the whirling of the combustion air can be utilized to impart a circular motion to the charge.

Fig. 889 is a section of an M.A.N. fuel-injector engine. By means of a cam-operated pump a the fuel is taken in and forced through the open nozzle into the combustion-chamber under a pressure of 300 atmospheres. The

simplicity of this arrangement is striking. The lateral injection results in a particularly simple construction of the cylinder-head, it leaves room for large valves, and it offers special advantages in car engines because of the convenient location of the nozzles. A particularly favorable feature is that there is no chance for the formation of air pockets because the fuel rises constantly from the pump to the combustion space.

M.A.N. Fuel Pump.—The fuel pump for a four-cylinder engine is cast in one block, for a six-cylinder there are two blocks of three cylinders each. Admission control is effected by opening a bypass valve during the delivery stroke of the pump, releasing pressure in the delivery pipe. This occurs early in the stroke when the engine is running light and late when running under load. The instant the overflow valve acts, the check valve of the fuel pump closes under spring pressure and the pressure prevailing in the engine cylinder. The fuel pump construction is shown at Fig. 890. To provide regulation of both power and ignition time the motion from cam

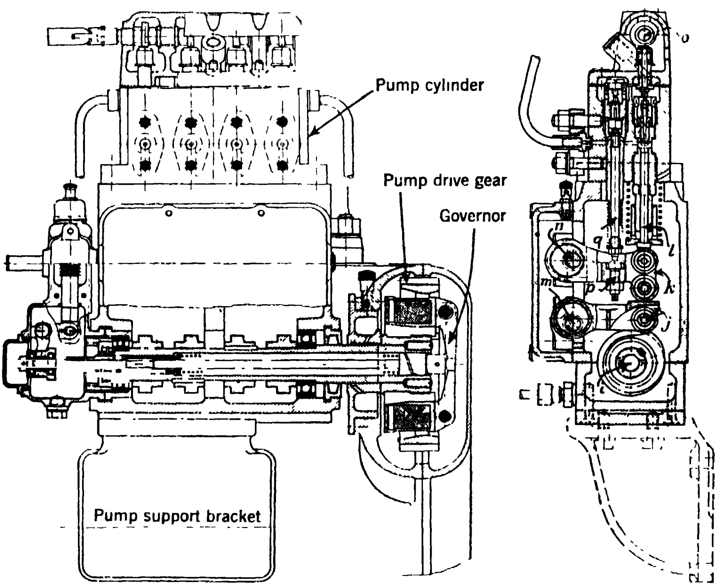


Fig. 890.—Sectional Drawing Showing the Construction of a Fuel Pump Serving a Four-Cylinder Automotive Diesel Engine. Note Engine Governor Mounted in Oil Pump Drive Gear.

i is transmitted through two levers j, k, which are fulcrumed on eccentrics, to the pump plunger l. Eccentric m of the lower lever causes a practically horizontal displacement of the roller on the cam and thus an earlier or later stroke of the plunger; in other words, early or retarded ignition. Eccentric n of the upper lever is shifted in an almost vertical direction, and thus changes the clearance between the setscrew p, in the lever, and the bypass valve q, in the pump body. The end of the useful stroke of the pump is governed by lifting the bypass valve off its seat sooner or later in the

stroke, according to the position of the upper eccentric. The fuel admission of the different cylinders will be uniform if the clearance between the overflow valve and the setscrew is the same, in the same relative crank position, for all cylinders. This also provides a very simple adjustment for the fuel pump. The fuel is taken in through a spring-loaded suction-valve above the pump plunger, which can be withdrawn upward for regrinding. In the two-spray arrangement, the check-valve is located in the fitting where the pipes branch off to the two nozzles. In the head of the fuel pump there is supported a shaft o, which, by means of staggered eccentrics, renders one or more of the cylinders inoperative by depressing the suction valves, so that the driver can determine while running whether the load is evenly distributed among the cylinders, or which cylinders are operating less effectively. The control rod from the governor mounted in the drivegear passes through the pump camshaft and actuates the upper eccentric through a bell-crank and a rack. The valves and pump plungers are hardened tool-steel and the pump liners are cast iron.

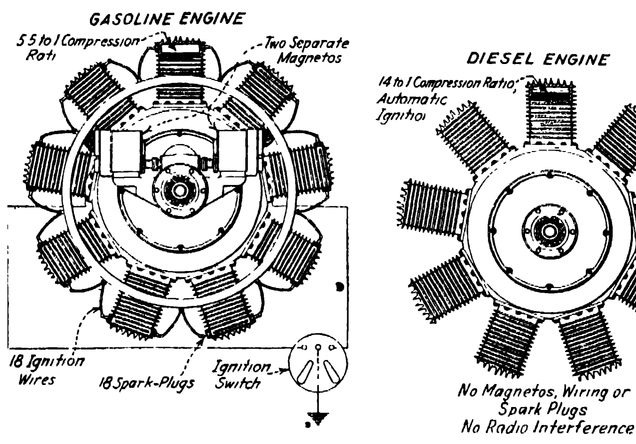


Fig. 890A.—Diagrams Showing Elimination of all Wiring on Compression Ignition Engine.

The high-speed Diesel vehicle engine first sold by the M.A.N. has 115-millimeter cylinder-bore and 180-millimeter stroke (4.53 by 7.09 inches). It is built with both four and six cylinders, and delivers 45 and 68 horsepower respectively, at a speed of 1,000 r.p.m. The weight of these engines is ten kilos (22 pounds) per horsepower. This type of engine, which is suited and has been used for many different purposes, is illustrated in Fig. 891. The crankshaft of the four-cylinder engine has three roller bearings, and that of the six cylinder has four roller bearings. In the aluminum crankcase are separate camshafts for the inlet and exhaust valves. The cylinders of the four-cylinder engine are cast in block and those of the six-cylinder engine in pairs. Cylinder-heads are attached to the cylinders by studs. Aluminum pistons are used and there are dust-proof aluminum covers over the engine, as shown in the photographs. It will be apparent

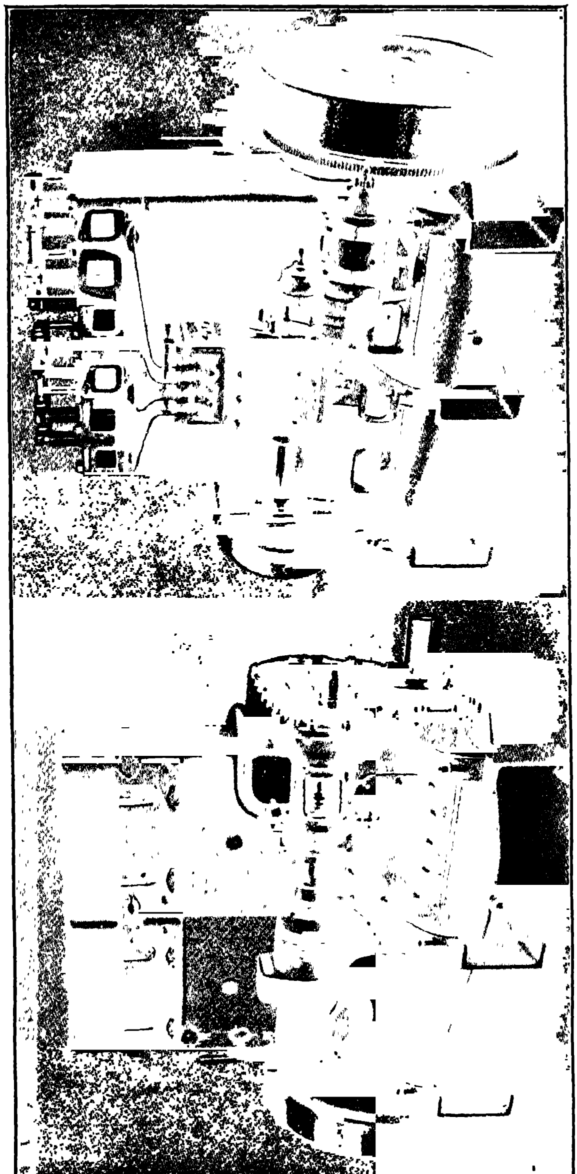


Fig. 891.—The M.A.N. Automotive Diesel Engine. View at Left Shows Water Pump and Generator; Illustration at Right Shows the Fuel Pump and Injection Nozzles.

that the weight must be greatly reduced to make engines of this type suited for airships.

A starting motor usually is provided with the engine, but for manual starting the exhaust valves can be raised from their seats. For starting after the engine has been standing idle in the extreme cold, air must be preheated for reliable ignition. The inlet pipe is provided with a butterfly valve to throttle the cold air while the engine is running idle or light, heated air being drawn from the exhaust pipe. The starting motor and generator, as shown in the illustration, are built outside the casing. The engine can be modified also for starting with compressed air.

Other models with greater power, 50 and 100 horsepower per cylinder at 700 r p m , are under construction, but no details of these are now available.

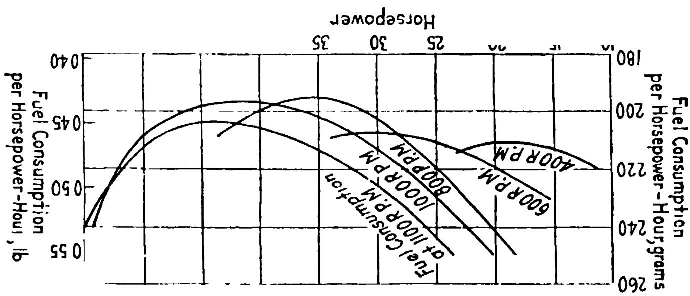


Fig. 892.—Curves Showing Fuel Consumption of Automotive Diesel Engine. The Metric Horsepower Shown in the Curves is 1.4 Per Cent Less Than English Horsepower. The Tests Were Made with a 4.53 Inch Bore and 7.09 Inch Stroke Engine.

Exhaustive experiments on the test block have given a rather clear idea of the suitability of engines of this type for automotive use, and of their efficiency. Results of fuel measurement at different speeds on the 115 by 180-millimeters (4.53 by 7 09 inches) size, with injection through two lateral nozzles, are shown in Fig. 892. These tests were made with a fuel having a rather low heat value of 9,930 calories. The specific fuel-consumption, at all speeds used, ranges between 200 and 215 grams (0.44-0.47 pounds) per horsepower hour, this being lower than the best values for gasoline engines. Compared with carburetor engines, the fuel consumption is very low over a long range of partial load, a fact that will be found particularly favorable for car propulsion where very low and medium loads are frequent.

The fuel used for the engine is a high-grade gas-oil, a pure distillate, free from crude-oil residues or the like. Among other suitable fuels are certain low-viscosity crude-oils, lignite tar-oil and shale oil. When the engine is used for driving vehicles, especially in large cities, a very light gas-oil having a boiling point not over 320 degrees Centigrade (608 Fahrenheit) is considered preferable, to prevent objectionable odor from prolonged idling of the cold engine, or from improper adjustment of the injector or the fuel pumps.

Owing to the high thermal efficiency, the volume of heat carried off by the cooling water is somewhat lower than in the carburetor engine. This property of the Diesel engine permits the use of a radiator smaller than is usual. Oil consumption is just as low as that of good carburetor engines, and the quality of the lubricating oil required is the same.

Saurer-Diesel Engine.—Automotive Diesel engines for trucks have been experimented with for a number of years by the Adolphe Saurer Co., of Arlon, Switzerland, and have been described and illustrated in *Automotive Industries*.

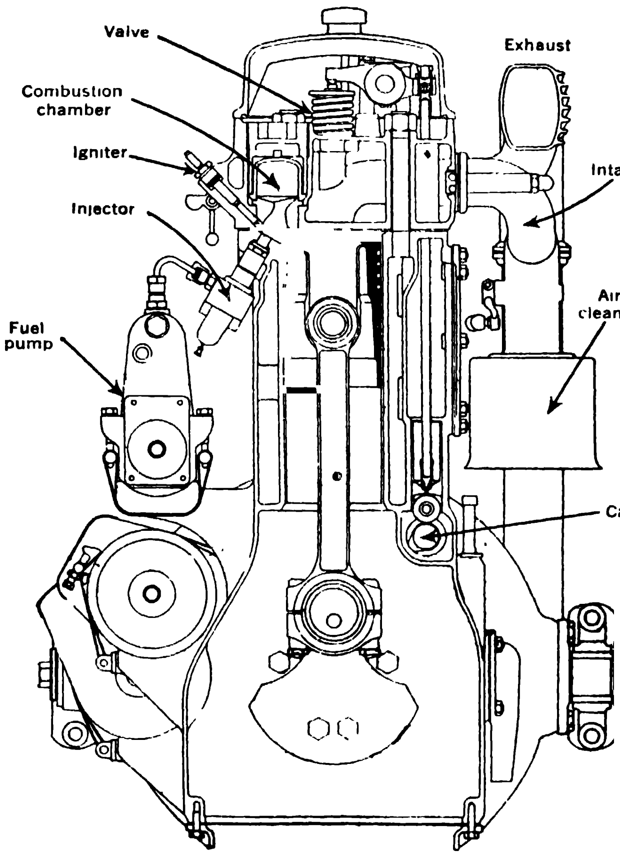


Fig. 893.—Cross Sectional View of the Saurer-Diesel Type Motor Truck Engine Which Weighs About Ten Pounds per Horsepower.

The final type of Saurer engine will be a six-cylinder, four-cycle of 110 by 150 millimeter bore and stroke. This engine was produced nearly a year ago as a gasoline type, but the design was laid out in such a way that practically all the essential parts could be used also for the Diesel model. Great rigidity is obtained by having cylinders and crankcase in one casting, this

casting also comprising the timing gear housing at the front, inclosed by a cover plate which carries the water pump and the ventilator fan. This latter has an oil-less Silentbloc bushing. The crankshaft is a built-up type carried in seven roller bearings, fitted with a vibration damper. The camshaft is carried in cast-iron bearings in the cylinder block and the valves are vertical in the head and operated by push rods and rockers. This engine develops 105 horsepower at 1,600 r.p.m., but recently, for a motor coach competition, was speeded up and made to develop 130 horsepower. It weighs 1,320 pounds or about ten pounds per horsepower.

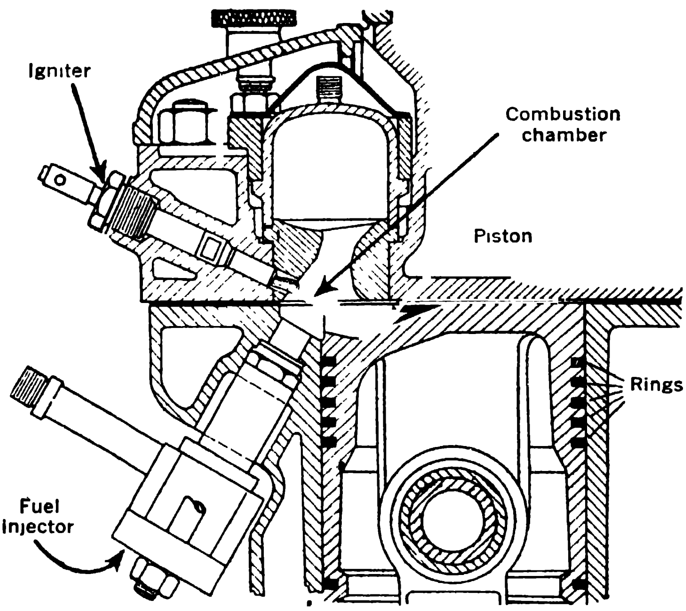


Fig. 894.—Details of Combustion-Chamber of Saurer-Diesel Automotive Engine.

As a Diesel type the essential parts of the engine remain unchanged, but a special head is used, with the normal valves, and mounted on the head is a bottle-necked spherical ante-chamber. As will be seen from the drawing, Figs. 893 and 894, air is compressed into this chamber, the volumetric ratio being 15.5, giving a theoretical pressure of 32 atmospheres, or 470 pounds per square inch. Fuel is injected into the ante-chamber, the flow being in the same direction as that of the air, which is contrary to the practice of certain German manufacturers of Diesel engines, who adopt the system of opposing currents. While the cylinder barrels and head are water cooled in the normal manner, the steel ante-chamber has no water jacket, and is held down by studs which allow for expansion. The six ante-chambers are all inclosed by an aluminum cover plate.

A pump, driven off the same shaft as the electric generator, has six pistons with an invariable stroke but a variable delivery of fuel. In addition

to a reciprocating motion, the pistons can be rotated on their axis by means of a hand control, thus cutting off the flow of fuel. Delivery always begins at the same point, which is probably 40 degrees before upper dead center, but the flow is cut off earlier or later according to engine speed. The fuel is injected into the ante-chamber at a pressure of 60 atmospheres.

Operation of this engine is no more complicated than that of the gasoline type, the only control being the throttle, which in this case regulates the cut off of the fuel supply. It is both foot and hand controlled.

Weight of the Diesel engines is practically the same as that of the gasoline model. Power output of the former is, however, about fifteen to sixteen per cent less than that of the latter. In the case of the existing four-cylinder Saurer engines, having a bore and stroke of 110 by 180 millimeters, the power output is 52 horsepower at 1,200 r.p.m. when running on gasoline and 44 horsepower as a Diesel. Although governed to this speed, the Diesel will run up to 1,600 or 1,800 r.p m. Another disadvantage is the difficulty of starting up from cold with the high compression ratio employed. At present the engines are warmed with hot water, an electric starter is used to swing them, and the charge is at first ignited by a hot plug through which an electric current is passed.

The proved advantages are much lower fuel cost, the ratio of costs, with fuel bought on the Swiss market, being five and one. It is claimed that the gas oil consumption on the Saurer-Diesel is 0.52 pounds per horsepower hour. The Saurer truck having a total weight of 8½ tons, of which 3½ tons constituted useful load was used for testing purposes and averaged just over nine miles to the gallon of gas oil, when running with full load, and improved this to thirteen miles to the American gallon when running without load. The gasoline motor of the same size, fitted in the same truck, averaged 6.7 miles to the gallon with full load and only improved this to 7.7 miles to the gallon when running light. It is stated that there is a greater degree of flexibility with the Diesel engine than with the gasoline type. The former could be started away under full load on third gear (a four-speed transmission was fitted); it would throttle down to four miles per hour, and it accelerated from 4.3 to 24.8 miles per hour in 62 seconds. The intermediate and final gear ratios were exactly the same on the two chassis. The cooling arrangements were the same on the two models and were fully adequate for long climbs on eighteen per cent gradients calling for the use of bottom gear.

Improved Air-Fuel Mixture Method.—F. Ernst Bielefeld writing in *Automotive Industries* describes a new method of air-fuel mixture that will result in more rapid burning and make higher speeds possible. In a paper presented to the Association for Fuel Engineering in Berlin on December 6, 1927, Wa. Ostwald reached the conclusion that "it seems equally promising to develop the carburetor-type engine to operate at higher compression ratios and partial combustion at constant pressure, and to develop the Diesel engine to operate at lower compression ratios and partial combustion at constant volume. Practically speaking, this would lead to a high-speed, medium pressure engine with pronounced pre- and after-combustion. It would almost seem as though it might combine fuel and engine to an economic optimum."

Whether the views of Wa. Ostwald are correct in every particular only the future can tell. It is open to question whether preignition (preinjection of the fuel) is always necessary. There is at least one method of operation which does not call for such injection ahead of the dead center. This is the new method of operation for Diesel engines known as rapid combustion with high atomization or the introduction of oil vapor with simultaneous positive supply of air to the fuel.

It is a fact that the combustion efficiency of a Diesel engine depends to a large extent upon the rapidity with which the combustion is completed. The more rapid the rate of combustion the shorter the time during which there are heat losses. The more highly atomized the fuel when it enters

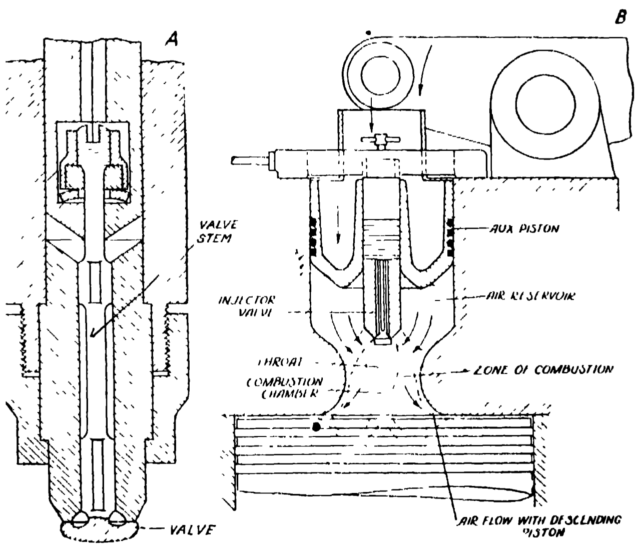


Fig. 895.—View at A Shows Bielefeld Injection Valve for Production of an Oil Fog. B is a Diagram of Bielefeld Diesel Engine Air Chamber with Cross Flow of Air and Fuel Currents.

the combustion-chamber the more rapidly the combustion can be completed However, when the fuel is so finely atomized that it is almost gaseous, it is impossible, even with the highest pump pressures, to give the jet such penetrating power that it will penetrate a flat combustion-chamber from an injection nozzle located in the center of the head.

It is therefore necessary to look for new means of carrying through the combustion in the short time available and in spite of the difficulty referred to. The air must be positively brought into contact with the fuel, in such a manner that every particle of fuel almost immediately comes in contact with the amount of oxygen necessary for its combustion. It is quite possible to carry out this plan in a Diesel engine.

First of all there is required a small poppet valve shown at A, Fig. 895, the lift of which is almost infinitesimal, and which is opened auto-

matically by the high pressure of the fuel oil. The combustion-chamber of the new engine as shown at B, Fig. 895, is of entirely different shape from that in the usual Diesel engine. It is divided into three sections. Above the piston head there remains a flat, disc-shaped space, the clearance space. The depth of this space is dictated by practical considerations, among which may be mentioned the increase in length of the piston with rise of temperature, as well as that of the connecting rod and crank arms. This clearance

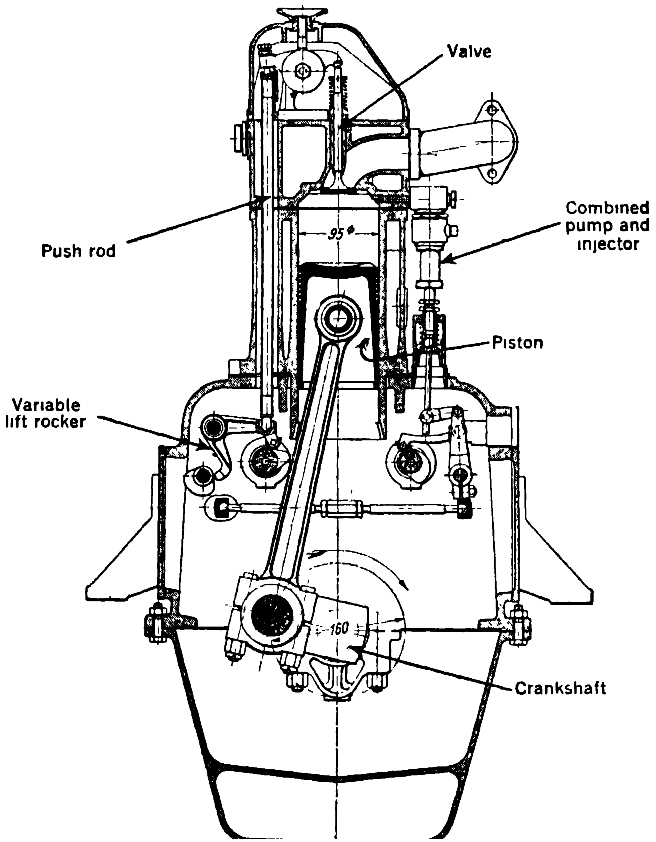


Fig. 896.—Cross Sectional View of the Dorner Constant Volume Diesel Engine.

space communicates on top with a neck. The injector valve extends close up to this neck. Above this neck there is the air storage space, so called because nearly the whole of the air necessary for combustion is stored in it. As soon as injection of the fuel begins the air is forced from the air storage space by an auxiliary piston, while at the same time the working piston begins its power stroke. As the working piston proceeds on its

downward stroke it increases the clearance space. Fuel is injected in such manner that it almost touches the wall of the neck. Therefore, an oil fog is spread in the neck of the combustion-chamber and a cross-flow of air and fuel currents is produced, forming a "fog net" in the neck of the combustion-chamber. Air driven through this oil fog by the auxiliary piston results in more rapid burning and makes higher speeds possible.

Packard-Dorner Diesel Aircraft Engine.—A Diesel engine, for the first time in history, became the motive power of an airplane on September 19, 1928. Actual test flights were made on that day by means of a 200 horsepower nine-cylinder radial air-cooled Diesel aircraft engine developed by the Packard Motor Car Company. The new motor was designed by Captain L. M. Woolson, Packard aeronautical engineer, in collaboration with Dr. Hermann Dorner, one of the foremost Diesel engine authorities of Germany. Mr. Adolph Widmann also assisted. The work was carried on under the direction of Col. J G. Vincent, vice-president of engineering of the Packard company. Walter Lees was the pilot and Captain Woolson a passenger in the first flight made at the Packard company's proving grounds at Detroit. The plane was a Stinson-Detroiter ship of regulation type. In view of the keen interest which this great event has justifiably aroused, the general engineering basis underlying the aeronautic Diesel engine is summarized in the following paragraphs, which are reproduced from *Oil Engine Power* for November, 1928. Although the exact constructive details of the radial engine are not being made public at this writing, it is assured that the Diesel combustion cycle as commonly understood was considerably modified in its design and operation in order to make possible a sustained output of 200 horsepower from an engine having only 600 pounds of metal weight. An engine which was designed by Dr. Dorner and built by Jüdel, Stahmer & Bruchsal embodies the new principles of operation and design which are regarded as characteristic of the new Packard engine and is shown at Fig. 896, though it does not represent the actual Packard engine, only the principles on which it is based.

The Dorner Diesel Principle.—Professor Dr. Ing Kurt Neumann gives an exhaustive mathematical analysis of the new method of applying the Diesel principle and supplements it with elaborate test data obtained from a Dorner J5B engine operated in accordance therewith. Among the radically new departures illustrated by these results are the attainment of 95.5 brake m.e.p. at 1,000 r.p.m. in a 3.76 inch by 6.29 inch cylinder operated at 1,000 r.p.m. 30 per cent thermal efficiency corresponding to 0.479 fuel consumption; air fuel ratio of 1.21 :1 ; exhaust temperature 1057 degrees Fahrenheit. These are some of the factors upon which the present reality of the flying Diesel engine is considered to be based.

In its general features the engine follows more or less stereotyped automotive lines; it will however serve the purpose of giving concrete embodiment to the new principles regarded also as the basis for the Packard-Dorner radial aeronautic engine. For the sake of maintaining absolute accuracy in the timing of injection it will be noted that a separate camshaft is provided for the fuel pump, while the camshaft for operating intake and exhaust valves is located on the opposite side of the engine. In view of the fact that the engine is operated with constant-volume combus-

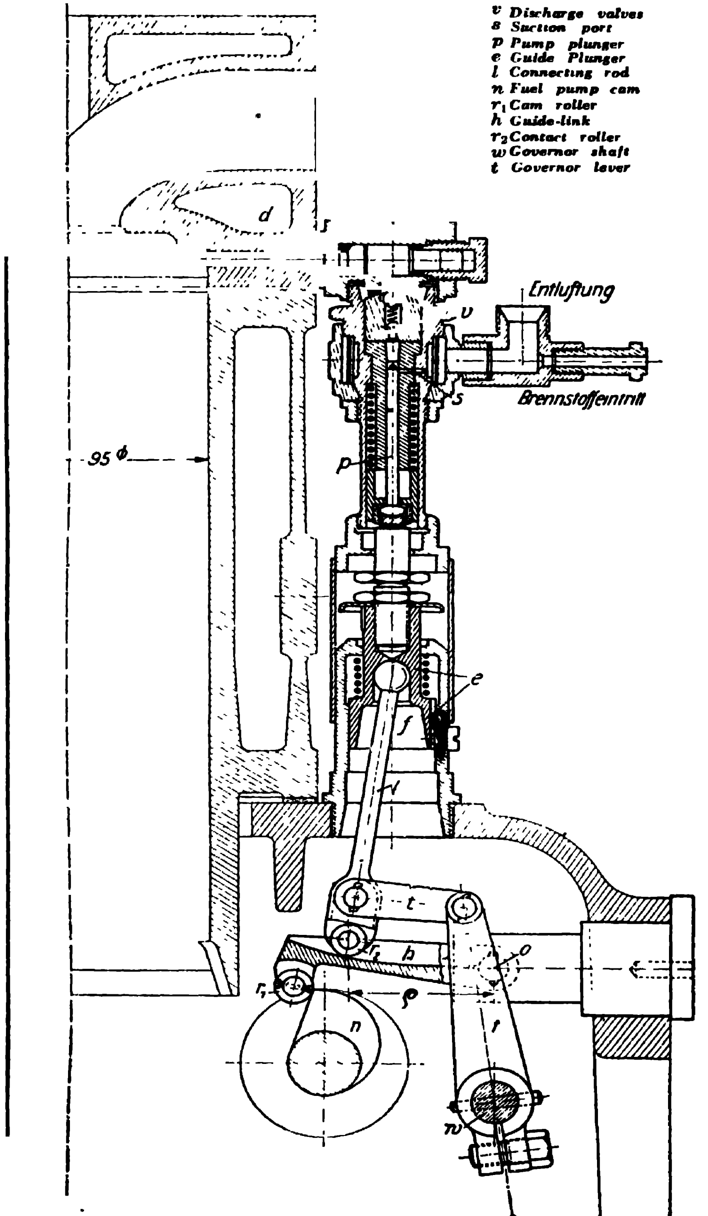


Fig. 897.—View Showing Construction of the Dorner Positive Acting Constant Lead Fuel Pump Believed Suitable for Automotive Diesel Engines. Relationship to Other Engine Parts Shown at Fig. 896.

tion precision in the control of injection timing is of considerably greater importance than in those designs when the use of mixed cycle combustion predominates. Further precautions for keeping the combustion confined as early as possible to the dead center are apparent in the cross section of the fuel pump and its drive shown at Fig. 897. The pump cam has a straight tangential rise of unusual length, while the method of altering the fuel pump stroke is such as to maintain constant lead and duration of injection for all loads. This is accomplished in the well-known manner by traversing the end of the pump push rod over a cam-roller guide-link having a contact

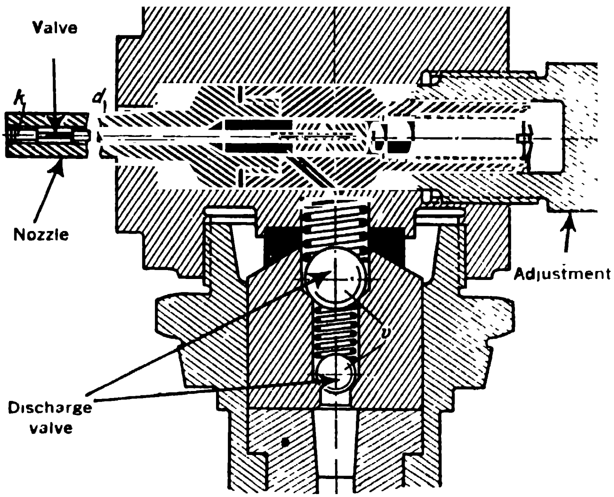


Fig. 898.—The Dorner Spray Nozzle Which is at the Top of and Adjacent to the Fuel Pump. Relationship of Parts to Pump Shown at Fig. 897.

surface with a radius struck from the upper end of the push rod as a center. The further the roller R_2 is moved away from the center O, the greater the effective stroke of the pump. The motion of the guide link H of course, remains unaffected, so that it always begins and ends its upward travel at the same crank-angles. The same is true of the pump plunger only the length of its travel is regulated. No suction valves are fitted to the pump, which draws in fuel by vacuum when the plunger P uncovers the drilled hole S at the lower end of its travel. Fuel enters through the horizontal passage marked Brennstoffeintritt immediately above which is located the air-vent (entuftung). Discharge valves consist of two spring-loaded hardened steel balls marked V, as may be seen from the enlarged cross section of the spray nozzle. The latter is mounted in the side of the cylinder very close to the discharge from the fuel pump, so that the disturbing effect of any kind of tubing and connections is eliminated. Were it not for this feature it is not probable that the requirements for constant volume combustion could be met as satisfactorily as the performance

of the system has indicated. The spray valve is of the poppet type that is opened towards the combustion space by the pressure of the fuel. Owing to its light weight and the extremely close connections between it and the fuel pump, it is estimated that its action follows the pump cam with a high degree of precision. The simplicity and general lack of special shapes in the combustion space will undoubtedly come as a surprise to those engineers who have regarded special contours of combustion spaces as indispensible requirements of all airless injection systems. The only irregularity consists in a shallow notch on one side of the dished piston crown; its purpose,

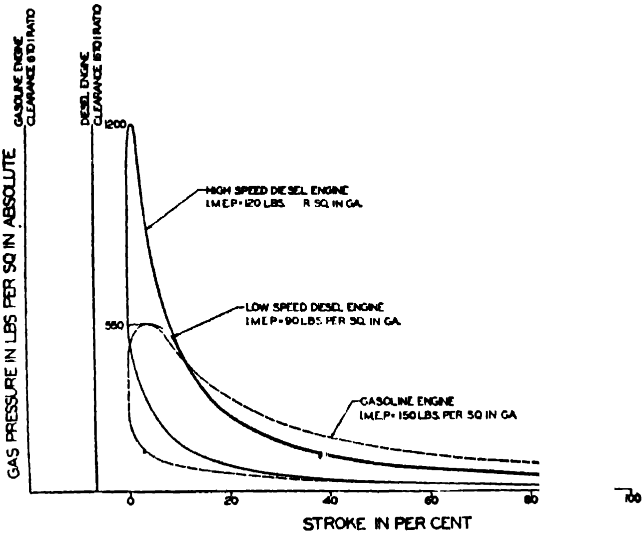


Fig. 898A.—Comparing Indicator Diagrams of High- and Low-Speed Diesel and Gasoline Engines.

however, is merely to provide an unobstructed path for the spray, rather than to set up air turbulence or to affect the combustion process in any other special way. Apparently the sudden pressure rise incident to the constant-volume combustion system is sufficient to create all needed turbulence, at least if with a 99-pound m.e.p. at 1,000 r.p.m., as was shown by careful measurements made at variable r.p.m.

Reduction in the weight of the Diesel engine to three pounds per *sustained* horsepower is illuminated by the thorough mathematical research of Professor Neumann already referred to. Whereas lower weights have been quoted for Diesel engines on the basis of output hoped for or attained with difficulty for short periods of time, the rating attainment of the Dorner engine was such as to stimulate an exhaustive analysis ultimately confirmed by test-bed results. Although it is impracticable to give a complete account of the work in these columns, it may be briefly indicated that they hinge

on applying the constant-volume combustion principle to the limit, regardless of consequences so far as maximum firing pressures are concerned.

Bearing loads and stresses in engine structures have hitherto deterred Diesel technologists from a thoroughgoing application of the constant-volume principle, although its effect in improving combustion and specific output attainable with combustion partially at constant pressure were known in a general way. It was argued that the resulting high pressures would compel designers to use heavier engine parts to withstand the forces and that weights would be unduly increased. Professor Neumann, however, shows that the constant-volume principle permits of increasing the mean effective pressure to such an extent that the extra horsepower gives good promise of overbalancing the additional weight as was confirmed by the Packard results.

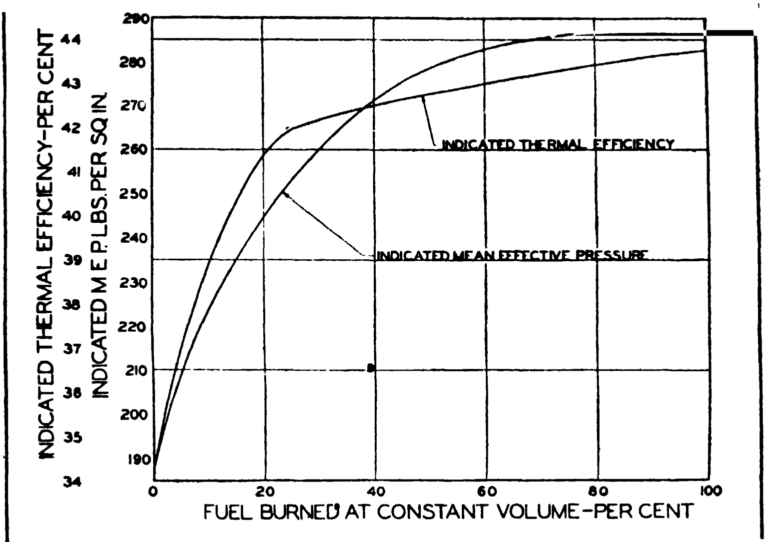


Fig. 898B.—Diagram Showing Indicated Thermal Efficiency of Diesel Engine.

The excess air ratio measured on test by means of a gasometer illuminate the performance of the Dorner engine from another angle. At full load the ratio of air drawn into the engine to the quantity theoretically necessary to burn the fuel injected was only 1.21:1. This figure gives a clear indication regarding the degree of material utilization characteristic of the engine and goes far towards explaining why it was the first Diesel engine type that ever took to the air.

Junkers Aircraft Diesel Engine.—Reference has been made to the Junkers-Diesel engines built for airplanes and airship use and several modern designs embodying the Junkers principles have been described in preceding chapters. Readers will be interested in the simple diagrams at Fig. 899 which show one of the designs experimented with by Professor Junkers at

Aachen, Germany, during the war. In this type, there are two crankshafts carried at the ends of the cylinders, one at each side of the motor with the cylinders between them. The cylinders each have two pistons and each piston is connected to its own crankshaft by the usual connecting rod. The engine shown is a four-cylinder form, there being a supplementary air pumping cylinder that also carries two pistons mounted at one end. The crankshafts are made to revolve in unison by a train of spur gears, a central gear having a projecting shaft to drive a propeller. The two pistons in each cylinder working in opposite directions, uncovered inlet and exhaust

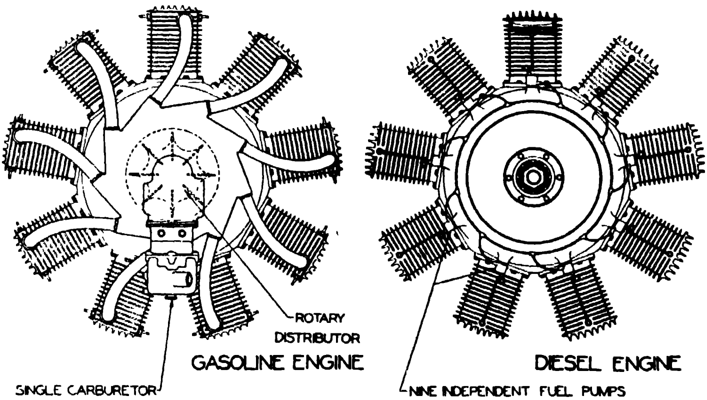


Fig. 898C.—Diagrams Comparing Fuel Supply of Diesel Radial and Gasoline Radial Engines.

ports near the end of their stroke. The exhaust port was uncovered first, and when the inlet port was uncovered, a compressed charge of air was forced through the cylinder by the integrally mounted scavenging pump, thereby practically clearing it of all burnt gases. Due to the excellent scavenging, good inertia balance, and absence of restricted valve area, it appears possible that Diesel engines of this type may be made to run at high speed and develop high mean effective pressures.

The weight-horsepower ratio can be made quite favorable because high resistance metals can be used, even though two sets of pistons, rods and crankshafts are necessary. It should be remembered that a four-cylinder engine of the type shown, because it operates on the two-cycle principle gives four impulses each revolution of the crankshafts and in turning torque it is equal to an eight-cylinder four-cycle engine which would have the same number of pistons and connecting rods. The cooling system was reported to be very effective. Working surfaces of the cylinders were completely surrounded by cooling water, and the pistons contained a cooling fluid that was said to greatly assist in the transmission of the heat from the head to the skirt where it was given up to the cylinder walls. Fuel supply was by injection pumps through spray nozzles of the simple type. One of the early four-cylinder engines developed in the Laboratories of Professor Junkers, was said to have developed 200 horsepower at 1,000 r.p.m. and to weigh

about 3.5 pounds per horsepower. The overall dimensions were as follows: length 52 inches, width 61 inches and height eighteen inches. A six-cylinder engine is also said to have been built experimentally, this would give the same number of explosions per crankshaft revolution as a twelve-cylinder

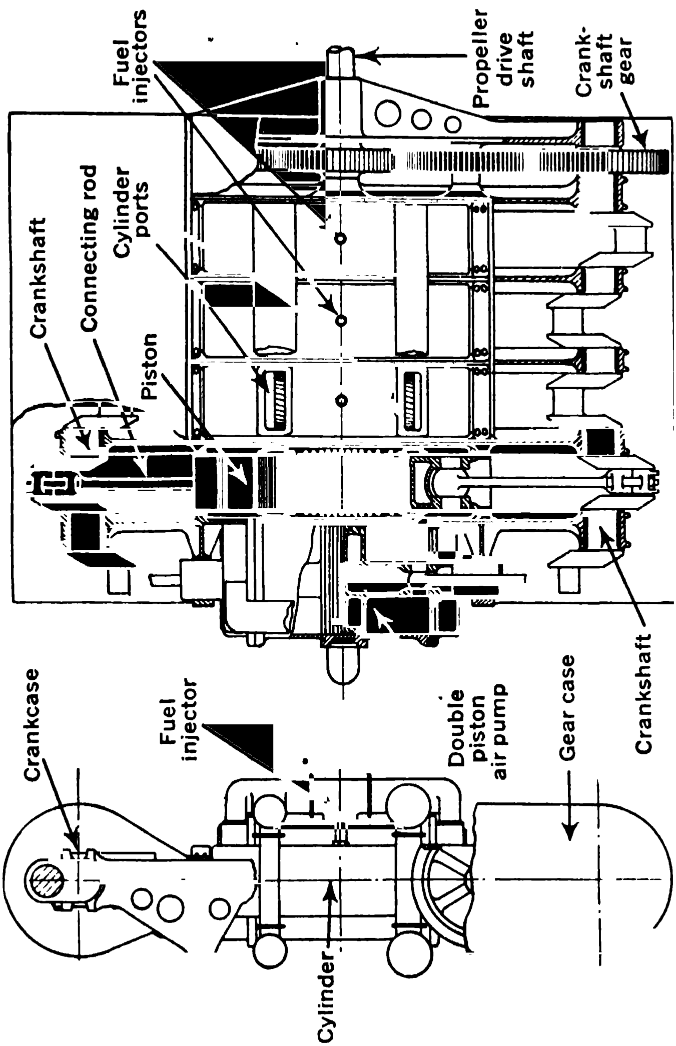


Fig. 899.—Diag Showing G al Construction of J ers Aircra
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four-cycle engine. The flat form of the engine makes it particularly well suited to installation inside of the Junkers thick wing section when used for airplanes and the writer feels safe in predicting that this form of engine, now undergoing intensive development, will be mounted inside the wings instead of outside.

Aeronautical Diesel Engines.—Captain L. M. Woolson, Aeronautical and Research Engineer for the Packard Motor Car Company, read a very instructive paper before the S.A.E. on the subject of Aeronautical Diesel Engines and outlined some of the advantages and experiences that his company found in developing and testing such an engine in co-laboration with Dr. Dorner, a German engineer of high standing who has had a wide experience in Diesel engine design. Captain Woolson stated that it has been assumed in many quarters that the high maximum cylinder pressures encountered with the high speed Diesel principle militated against sufficiently light engine construction to permit its usage for aircraft powerplants. That this fear is unfounded is perhaps best proved by the fact that the Packard-Diesel aircraft engine, weighing less than three pounds per horsepower, has been subjected to considerable flight testing as well as several hundred hours of ground testing, and a construction has been evolved which is fully capable of withstanding cylinder pressures well in excess of 1,200 pounds per square inch without having recourse to excessively heavy construction.

Departures from conventional aircraft engine design were, of course, required in many instances, but in general the result has been achieved by utilizing materials of the kind best suited to cope with the respective stresses and proportioning the structure in a manner calculated to secure maximum strength with minimum weight. As a typical example, it has been necessary to forego the use of the light cast alloys where subjected to alternating stresses, due to the low impact value of such material.

While the Packard-Diesel engine has been successfully flight tested as well as shop tested, evidently it is not perfected to the point where it is commercially applicable to all types of aircraft and as no details or illustrations of the Packard-Diesel engine were given, it is safe to assume that its makers were not ready to announce its perfection or availability to the trade at the time of presentation of the paper in December, 1928, and that more development work must be done.

Aeronautical Oil Engines Not True Diesel Types.—It is perhaps not generally recognized that the Diesel engine operating on the constant pressure cycle is limited by that very restriction to comparatively low-speed operation. All combustion phenomena taking place in internal-combustion engine operation require a definite time for their completion. Now it is perfectly obvious that any engine suitable for aircraft propulsion must be of the high-speed type. It must operate at speeds in excess of 1,400 or 1,500 r.p.m. in order to begin to compete with existing gasoline aircraft powerplants. Granting then that a practicable Diesel aircraft engine must run at speeds five or six times as fast as the stationary or marine type of Diesel powerplants, whereas the ignition time lag is substantially the same in either case, it can be readily seen that the high-speed engine demands a different type of combustion than the low-speed Diesel. Indicator diagrams comparing high- and low-speed Diesel engines with the gasoline engine are given at Fig. 898 A.

Fuel injection in the high-speed Diesel must start as early as 50 degrees before top dead center in order to insure complete and smokeless combustion, whereas in the low-speed Diesel fuel injection usually starts

about ten degrees before top dead center and continues until about 32 degrees past top dead center.

Now in the case of the high-speed Diesel, when ignition starts considerably ahead of top dead center, the cycle of operation does not materially differ from that of the gasoline or explosion engine, the spark of which is timed to occur at substantially the same point in the piston stroke that the fuel injection of the high-speed Diesel is timed to start. There is, of course, this important difference that when the spark takes place in the gasoline engine all of the fuel charge is contained in the cylinder, whereas when ignition starts in the high-speed Diesel engine only a small percentage of the fuel charge has already been injected. This latter condition enables the designer to control the pressure rise within the cylinder within certain limits.

Now since the high-speed compression-ignition solid fuel injection aircraft engine referred to throughout Captain Woolson's paper is termed a Diesel engine, an explanation might be in order to satisfy the criticisms of those who strenuously oppose the use of the term "Diesel" as applied to engines which do not operate on the true constant pressure cycle. Authorities the world over have sought to differentiate between the Diesel cycle and the so-called dual or mixed combustion cycle or Sabathe cycle in which the fuel is burned partly at constant volume and partly at constant pressure. The high efficiency of the mixed cycle has also been proved in a practical fashion by specific fuel consumption readings as low as 0.35 pound per brake horsepower per hour which have been obtained both by British experimenters and Dr. Dorner. Incidentally, it is interesting to note that, as numerous authorities have pointed out, an improved thermal efficiency results from the use of the mixed cycle rather than the original Diesel constant pressure cycle. The efficiencies obtained by burning fuel at constant volume, according to Trieber are given in diagram Fig. 898 B.

Factors Making for Greater Reliability.—Captain Woolson, after differentiating between the true Diesel cycle and the mixed combustion cycle found practical for aeronautic use, then made comparisons with gasoline engines on the basis of reliability. The Diesel engine scores heavily in respect to the two most important accessories of the internal-combustion engines, namely, ignition and carburetion or fuel supply systems.

Considering first the question of ignition reliability, in a nine-cylinder radial engine, there are necessitated two independent sources of ignition current whether of the battery or magneto type, two drives for these systems, eighteen high tension wires, eighteen sparkplugs and an ignition switch, comprising an aggregate of perhaps 1,000 individual parts. The Diesel engine ignition is furnished solely by the compression of the air charge and necessitates merely a smaller clearance volume in the cylinder as compared with the gasoline engine. No additional parts of any kind are required and continuous ignition is assured just as long as the engine is operating, whether it be for one hour or 1,000 hours. Furthermore, the ignition system of each cylinder is entirely independent of that of the others so that the nine-cylinder radial Diesel can be said to have nine individual ignition systems, whereas the gasoline engine of similar type is dependent upon the functioning of two independent systems, each comprising a great

many frail parts subject to failure, not forgetting the possibility of the sparkplugs failing to function due to the presence of carbon or oil on their surface.

Comparing the two types of engines now from the standpoint of fuel charge supply, Fig. 898 C illustrates the next important advantage of the Diesel engine in that each cylinder is furnished with an individual injection system, whereas the conventional nine-cylinder gasoline aircraft engine is dependent either on a single carburetor or on a triple-barrel carburetor. In the case of the single carburetor installation, this is usually complicated still further by the need for a rotary distributor of some kind or a low pressure supercharger intended to improve the distribution.

Lubricating Oil Burned Instead of Carbonized.—Captain Woolson then brought out the fact that any excess of lubricating oil in a gasoline engine combustion chamber is naturally considered extremely undesirable, as the temperatures on the walls are not sufficiently high to burn the oil completely, resulting in the formation of carbon and trouble with sparkplugs from this source, whereas in the Diesel engine the temperatures are considerably higher and, there being invariably an excess of oxygen available, perfectly clean combustion of lubricating oil follows. While excessive oil consumption in a Diesel is naturally to be avoided owing to the high cost of lubricating oil as a fuel, nevertheless it is interesting to realize that so far as the total weight of the oil consumed is concerned it matters very little whether this consists of lubricating or fuel oil, so far as miles per pound of oil carried is concerned.

Diesel Cooling Not Difficult.—From a cooling standpoint the air-cooled Diesel engine presents far fewer problems than the air-cooled gasoline engine. In the first place, high cylinder head temperatures, which must be avoided in the gasoline engine in order to prevent preignition and detonation, offer no serious handicap to the Diesel engine designer. Similarly, exhaust valve conditions appear to be far more favorable in the Diesel engine than in the gasoline engine, for the reason that exhaust gas temperatures are considerably lower, due to the high expansion ratio employed and for the same reason there is a considerable diminution of noise due to the exhaust. There is very little visible flame ejected from the exhaust ports, and it has been found quite feasible to fly the Stinson-Detroiter equipped with the Diesel engine without exhaust stacks or manifolds, thus eliminating a knotty design problem which is a continuous source of worry to airplane designers.

Diesel Engine Runs in Any Position.—An interesting point of advantage in connection with a Diesel aircraft engine is the fact that it will operate successfully in any position. All carbureting engines are dependent upon gravity so far as the correct functioning of the carburetor is concerned, and consequently the gasoline engine will not continue to run beyond certain angles of inclination dependent upon the carburetor design.

The acceleration of the Diesel aircraft engine is at all times excellent, regardless of the temperature conditions or how long the engine has been idling. This is in marked contrast to gasoline engines, which must be carefully nursed on a long glide, especially in cold weather, to insure the engine accelerating promptly in the event of full engine power being required

previous to making a landing.

Diesel Engines Not Affected by Rain.—Another interesting point in connection with the operation of a Diesel aircraft engine is that it is not affected by rain or water in quantities which would seriously interfere with a gasoline engine. Primarily, of course, this is because there are no high tension electric currents to be short-circuited by water, but the question of a single carburetor air inlet also enters.

For example, in taking off with a seaplane it frequently happens that just at the critical instant when the plane is about to get up on its step and every bit of available power is required, considerable water will be either shipped into the carburetor, which on the average air-cooled engine necessarily will be in a low and therefore disadvantageous position, or the propeller will pick up water with the same result, and the engine will naturally choke and lose revolutions, necessitating a fresh start.

A Diesel aircraft engine has been run for many hours without the slightest disturbance in excessively heavy downpours, which would undoubtedly cause serious missing, if not stoppage, of a gasoline engine.

Diesel Inherently Reliable.—Granting then that both from an ignition and fuel-feeding standpoint the outstanding advantages of the Diesel lie in its inherent reliability, Captain Woolson is prepared to consider the point that a single Diesel engine plane has all the reliability characteristics of a three-gasoline-engine plane. The three gasoline engines would each be equipped with two ignition systems, making a total of six independent ignition systems, whereas the single Diesel engine with its nine cylinders would have nine independent ignition systems with the added advantage that the Diesel ignition system requires no additional parts on the engine and each gasoline engine ignition system consists of several hundred separate parts. The three gasoline engines will have three independent carbureting systems; the single Diesel engine will have nine independent fuel injection systems, so that here again on the score of reliability gained by duplicating important elements the Diesel engine possesses a wide margin over its competitor. Taking all things into consideration, and without reference to the important aerodynamic advantages of the single-engined plane, it would appear that the advent of the Diesel aircraft engine brings about the necessity for thoroughly reviewing the subject of single versus multi-engined planes.

Captain Woolson then considers other parts of the engine from the standpoint of reliability, and to do justice to this phase he outlines one new distinction between the operation of the Diesel and the gasoline engine. Maximum cylinder pressures in the Diesel are absolutely fixed by the design and these are not varied appreciably by a wide range of different fuels. Maximum cylinder pressures in a gasoline engine may vary over a range as high as three to one considering the case of an engine detonating either due to a poor grade of gasoline, hot exhaust valves, hot sparkplugs or over-heated cylinders. In other words, detonating pressures in a gasoline engine approximate the maximum cylinder pressures of the Diesel aircraft engines, but it should be noted that the Diesel engine is designed and ground-tested to withstand these pressures over long periods of time, whereas the gasoline engine is invariably ground-tested under ideal conditions with detonation suppressed. On the other hand, it frequently hap-

pens than an aircraft gasoline engine of relatively high compression will be operated on commercial motor gasoline due to inability to secure a supply of aviation gasoline, and it thus becomes necessary for the pilot to fly considerable distances with the engine detonating, or in normal operation detonation may set in due to failure of one ignition system, or other causes. These detonating pressures in a gasoline engine, for which the engine is not designed, will invariably result in serious damage to the engine if allowed to persist for any length of time. Piston seizure is quite common from this cause, and crankshaft failure by no means unknown.

Reliability Reduces Number of Engines Required.—The point emphasized in Captain Woolson's paper is that the gasoline engine is occasionally abused either through carelessness or as a result of an emergency, so that it is very liable to failure from this cause. The Diesel engine cannot be abused, as there is no way in which the operator can increase the maximum cylinder pressures over those which the engine was designed to meet. Consequently, apart from considerations of ignition and carburetion reliability, it may be necessary to employ three gasoline engines to provide the utmost dependability on account of the fact that the engines can be abused and to that extent are not fool-proof, whereas one Diesel type with its reputed greater reliability will suffice, within reasonable limits, to supply power. Of course, if the airplane is a large transport type, it may be necessary to use more than one engine in order not to concentrate all powerplant weight at one point and to make proper allowances for limitations in propeller design, regardless of the combustion cycle employed.

Economy of Diesel Engine.—A very instructive table was presented by Captain Woolson to show the relative cost of one brake horsepower with various fuels in different types of internal-combustion engines and shows the unquestioned economy of the Diesel compression ignition cycle. The tabulation follows:

COST OF ONE B.HP./HR. WITH VARIOUS FUELS IN DIFFERENT TYPES OF INTERNAL-COMBUSTION ENGINES

Type of Engine	Fuel	Comp. Ratio	Lb. Per Gal.	Spec. Gr. Be.	Cents Per Gal.	Cents Per Lb.	Lb. Per B Hp/Hr.	C
Otto Cycle Spark Ign	Kerosene	4:1	44	12.7	6.72	1.89	.80	1.51
Otto Cycle Spark Ign	Motor Gasoline	4 5:1	59	14.8	6.17	2.40	.65	1.56
Otto Cycle Spark Ign	Ethyl Mtr. Gas.	5.5:1	59	17.8	6.17	2 88	.60	1.73
Otto Cycle Spark Ign	Aviation Gasoline	5.5:1	63	19.8	6.04	3 28	.52	1.70
Otto Cycle Spark Ign	Ethyl Av. Gas.	7.1	63	22.8	6.04	3.78	.48	1.82
Comp. Ign. Diesel Cy.	Furnace Oil	12-16·1	38	10.2	6.94	1.47	.38	.56
Comp. Ign. Diesel Cy.	Diesel Oil	12-16:1	24	7.0	7.57	.93	.38	.35

In the final analysis any transportation system must justify its existence on economic grounds, and the cost of operation of a single-Diesel-engined plane as compared with a three-gasoline-engined plane must be in the order

of at least one to four which constitutes an inducement which no transportation executive can afford to ignore.

Summary of Diesel Advantages.—Summing up, Captain Woolson states the advantages of Diesel engines for aircraft may be covered in the following statements:

1. The Diesel engine is inherently far more reliable than the gasoline engine because:
   (a) The electrical ignition system is entirely eliminated.
   (b) A separate fuel injection means is applied to each cylinder insuring maximum dependability.
2. The fire hazard is reduced to the absolute minimum.
3. The specific fuel consumption is reduced about twenty per cent.
4. The specific fuel cost is reduced about 70 per cent.
5. Open exhaust ports, eliminating the weight and drag of exhaust manifolds, are permissible, both from noise and night flying vision standpoints.
6. Engine operation is not affected by temperature or humidity conditions; flexibility of control is assured at all times.
7. Radio interference is eliminated.
8. Basic reliability of the Diesel engine justifies a reduction in the number of powerplants in large planes and presages a consequent important reduction in the cost of maintenance and operation of commercial air transportation facilities.

An Important Disadvantage.—On the basis of power output per unit of piston displacement the Diesel aircraft engine falls considerably short of the best gasoline engine practice. Expressed in other terms, brake mean effective pressures as high as 130 to 140 pounds per square inch are readily obtainable in well-designed gasoline engines, whereas 100 to 110 pounds brake mean effective pressure can be considered a good achievement with a high-speed solid fuel injection oil engine. However, in this connection it should be borne in mind that these latter figures apply to the rated power output of the Diesel engine which it is capable of sustaining for long periods and which takes into consideration the need for perhaps 25 per cent excess air over and above that required to furnish sufficient oxygen to combine with the fuel and thus insure complete combustion.

QUESTIONS FOR REVIEW

1. How do engines intended for dirigible balloons differ from airplane engines?
2. How are engines mounted in dirigibles?
3. How is water ballast obtained from exhaust gas?
4. Describe reversing feature of Maybach dirigible engine.
5. Why is it possible to use reverse gears on dirigibles and not on airplanes?
6. Outline construction of Packard dirigible engine.
7. How much power does a dirigible need?
8. Describe advantages of Diesel engines for aircraft.

CHAPTER XLVI

UNUSUAL INTERNAL-COMBUSTION POWERPLANTS

Two-Cycle In-Line Type—Two-Cycle Vee Type—Rotary Two-Cycle Engines—Piston Distributor Two-Cycle Engine—Early Static Radial Engine—Variable Compression Rotary Engine—Double Acting Rotary Engine—Double Rotary Engine—Barrel Type Engine—Fan Type Engines—X Type Air-Cooled Engine—Engines with Integral Cooling Systems—Engines with Built-in Cannon.

In the course of his professional practice, the author has had numerous designs of engines submitted to him for analysis and report by sanguine inventors who believe they have discovered some new principle or arrangement of parts that will give much superior results to the conventional arrangements used by the designers of the engines commonly employed. In most cases, the designs submitted not only have had no advantages but were more complicated in construction or less efficient than the tested and well developed designs described in preceding chapters.

Several principles are very attractive to inventors and the same thing is often invented over and over again. One of the most attractive types to receive consideration is the two-cycle engine in its various forms. Engines of the in-line type and both static and rotary radial two-cycle forms continue to receive attention. Then we have inventors who believe that combining the water cooling system with the engine without using a separately mounted radiator will simplify the assembly. Another group spends much time and effort designing various types of barrel engines in which a more compact grouping of the cylinders than is possible with the usual radial arrangement is sought. It is the writer's opinion, based on considerable research work, that it will be difficult for an inventor to find some form of engine or cylinder arrangement that is not already patented or that has not been reduced to practice. In this chapter, various unusual forms of engines that have been built and tried, some with considerable success and others that have developed grave faults will be illustrated and briefly described for the benefit of the student-engineer and the practical man who has inventive genius.

Two-Cycle In-Line Type.—One of the types that seems to be very attractive to inventors is the two-cycle of the three-port type, with or without rotary distributor valve. These are by no means new as the Roberts 100 horsepower engine shown at Fig. 900 was built during 1911 by Mr. E. W. Roberts, one of the pioneer engine designers at Sandusky, Ohio. These early engines had alloy cylinders made of Aerolite metal and were of the usual three-port type. The Model 6X illustrated was a later form and had six vertical cylinders of five inch bore and stroke and developed 100 horsepower at 1,200 r.p.m. The weight was said to be 350 pounds or 3.5 pounds per horsepower. The cylinders were cast iron with integral water jackets and aluminum pistons were used. The crankshaft was supported by seven plain bearings. Two carburetors were used, one for each three cylinders and ignition was by battery or magneto. The fuel consumption was given

as .63 pounds per horsepower-hour and oil consumption was given as .047 pounds per horsepower-hour. A number of successful flights were made with these engines and they were also used for motor boat racing. The large fuel consumption was a disadvantage as well as the fact that after such engines had run enough to wear the main bearings, the crankcase pressure was reduced and prompt bypass of the gas from the crankcase

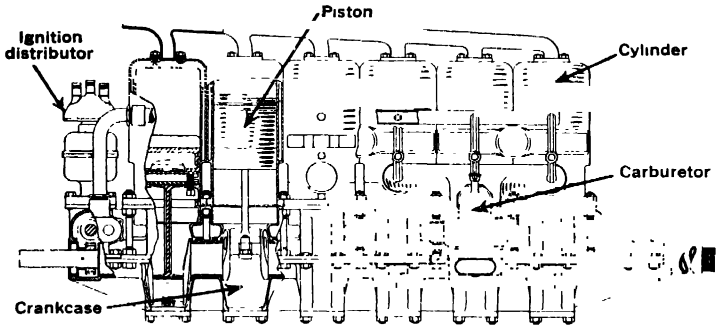


Fig. 900.—The Roberts Six-Cylinder Two-Cycle Airplane Motor, an Early Form that Made Successful Flights.

to the cylinder was interfered with. These engines were replaced by lighter and more efficient powerplants of the four-cycle type. The engines were smooth running and the six cylinder form shown gave the same number of impulses per crankshaft revolution as the twelve cylinder four-cycle did.

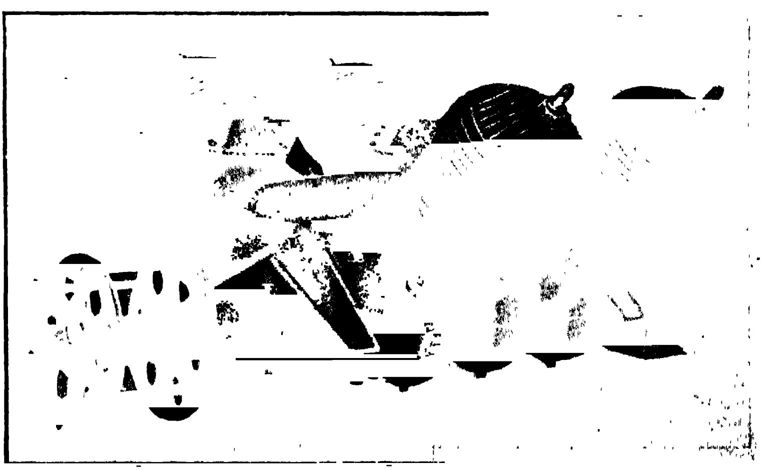
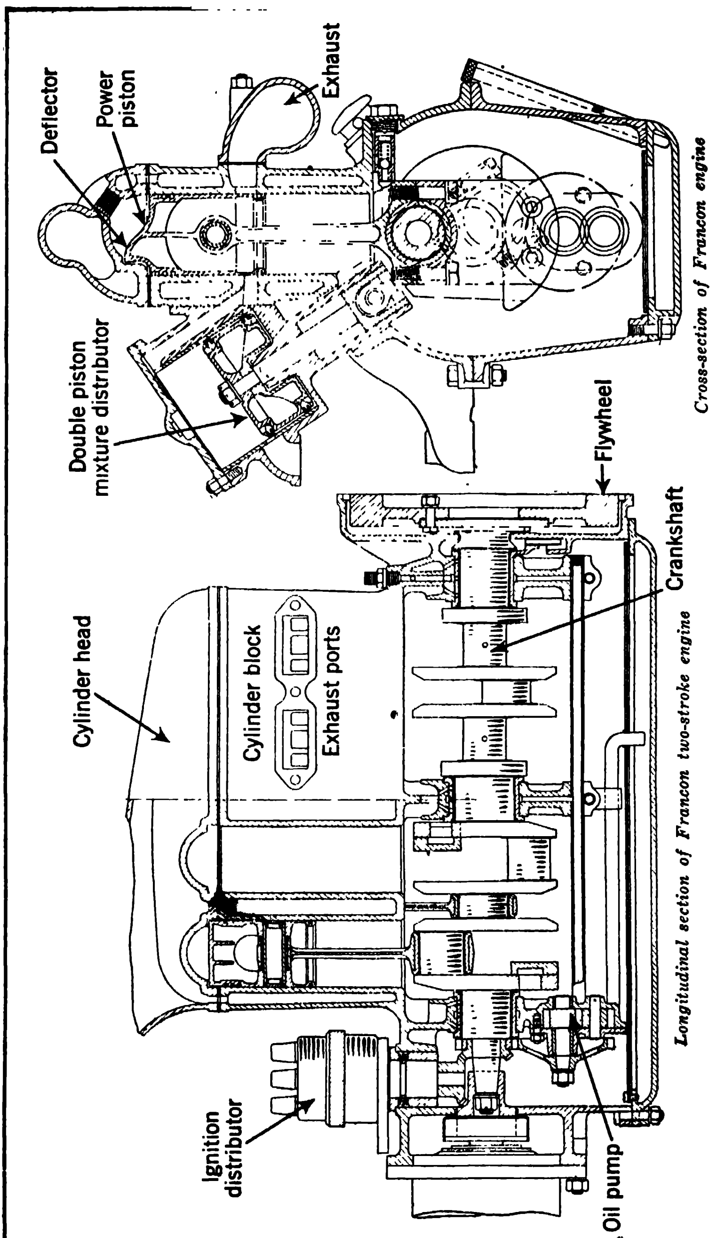


Fig. 901.—The W.B.B. Four-Cylinder "Vee" Two-Cycle Air-Cooled Engine Designed for Sperry Aerial Torpedo.

Two-Cycle Vee Type.—The two-cycle engine shown at Fig. 901 was known as the W.B.B. It was designed by C. Harold Wills of Detroit during the war and was intended for a special aerial torpedo, wireless con-



Cross-section of Francon engine

Longitudinal section of Francon two-stroke engine

Fig. 902.—The Francon Two-Cycle Engine Uses Piston Type Mixture Pump.

trolled, that was experimented with by the Sperry Gyroscope Co. To secure light weight, the engine was constructed largely of aluminum, the air-cooled cylinders having liners of steel pressed into place. There is no record of this engine having been fitted to a passenger-carrying airplane though the aerial torpedo it was designed for was an airplane having a capacity of 250 pounds of explosive.

Piston-Distributor Engine.—A piston distributor and a special type of deflector assuring a high degree of turbulence are among the features of a two-stroke engine produced by the Francon Co. of Paris, under Chedru patents and described in *Automotive Industries*. The engine is a four-cylinder of 61 cubic inch piston displacement, having a bore of 62 millimeters and a stroke of 82 millimeters. The fresh gases are admitted and the spent gases are exhausted through ports uncovered by the power piston. This latter is fitted with a deflector of such shape that, as will be

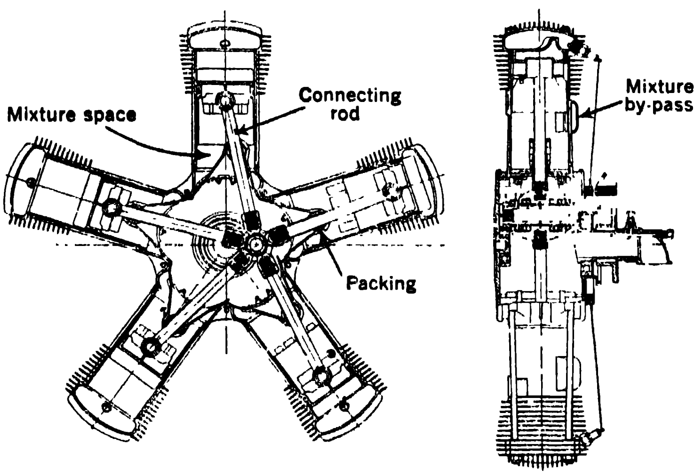


Fig. 903.—The Frederickson Rotary Two-Cycle Radial Air-Cooled Engine Was an Unusual Design.

seen from the drawing at Fig. 902 it sets up a high degree of turbulence in the combustion-chamber. The detachable cylinder head is spherical and completely machined, and has the sparkplug inclined in it. It is claimed that this feature alone results in a considerable increase in power and greatly improved slow running compared with the normal type of deflector. While the form shown has been designed for automobile use, modifications of this design have been proposed for aircraft.

Crankcase compression is avoided, and as a consequence a normal type of high pressure lubrication can be adopted, by the use of a piston distributor putting the carburetor into communication with the intake port. For the four-cylinder engine there are two such distributors, driven by eccentrics off the crankshaft. These pistons operate in supplementary cylinders, having a bore of 90 millimeters, inclined on one side of the engine, and are of the double ended type. Both the upper and the lower faces are

perforated, the gases entering behind the ring, passing through the holes, thus being atomized and then into the combustion-chamber. The upper face of the piston communicates with one cylinder, and the lower face with the companion cylinder. The engine has a compression ratio of 5.5.

Rotary Two-Cycle Engines.—A number of designers have built rotary two-cycle engines and ingenious methods have been used to secure the compression necessary to insure gas transfer from one end of the cylinder to the other without using a supercharger or separate air pump.

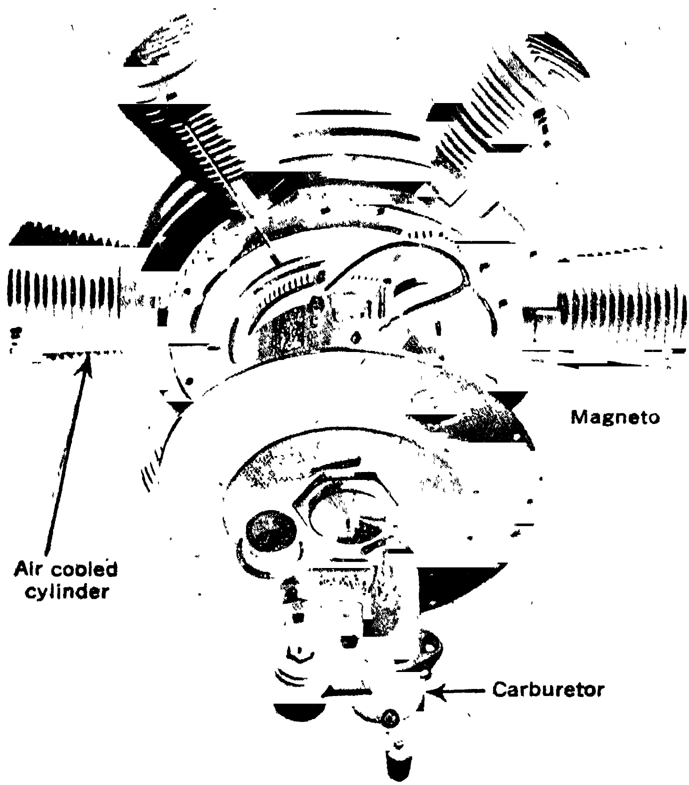


Fig. 904.—Rear View of Ajax 80 Horsepower Rotary Radial Two-Cycle Air-Cooled Motor Showing Supercharger Case, Magneto and Carburetor.

The Frederickson engines, one of which is shown at Fig. 903, built at Bloomington, Illinois, were two-cycle air-cooled rotary engines of five and ten cylinders and known as Model 5a and Model 10a, respectively. The bore was 4.5 inches and the stroke 4.75 inches. The five-cylinder engine was rated 70 horsepower at a normal speed of 1,000 r.p.m., and reported to weigh 180 pounds, or 2.57 pounds per rated horsepower. The total displacement was 377.7 cubic inches. The ten-cylinder model of 755.4 cubic inch displacement was rated at 140 horsepower. The cylinders were made with integral cooling fins from cast iron and supported from

the head by steel rods. The crankcase contained the curved seats for the valves which closed the inner end of the cylinders. The valves extended into the cylinders and were operated by the oscillating motion of the connecting rods which passed through them. The gas was drawn from the carburetor through the crankcase and oscillating valves into the inner end of the cylinders. There was no compression in the crankcase, the gas being compressed in the inner end of the cylinders and transferred by means of a bypass to the outer ends where it was compressed and fired in the usual manner.

The Aircraft Holding Corp., Los Angeles, Cal., is producing a new type of radial air-cooled aircraft motor. The 120 horsepower size known as the "Atlas" is a rotary radial having eight cylinders and weighs with its supercharger 260 pounds. This size was decided on to provide a moderate-priced powerplant for an airplane which will carry three people, a small amount of luggage, four hours' fuel and have a ceiling of 16,000 feet. The second size shown at Fig. 904 is known as the "Ajax." This is a six-cylinder 80 horsepower size for the popular European light plane types now in extensive use as instruction machines, flying club equipment and pleasure planes for private owners. Such types usually carry two people and have a gasoline consumption of from fourteen to twenty miles per gallon.

These engines operate on the two stroke principle, each cylinder giving a power stroke to the propeller shaft every time the piston rises to the head of the cylinder. This makes a total of eight power strokes per revolution in the 120 horsepower size as against half this number for a valve motor having the same number of cylinders and working on the four-stroke principle and six on the size illustrated.

Due to the absence of valves and extensive cylinder head mechanisms the motor has a fifteen per cent smaller overall diameter than an equivalent radial motor having valves. The entire absence of openings in the cylinder heads eliminates the possibility of oil escaping and covering the occupants of the plane. The cylinder head is machined integral with the barrel, the only openings being the sparkplug holes.

Specifications on the "Atlas" are as follows: Bore, 4⅞ inches; effective stroke, 4¾ inches; full stroke, six inches; compression ratio, 5.2 to 1; r.p.m. 1,250; weight 260 pounds. Gasoline consumption averages .52 pints per horsepower hour. Oiling is by force feed from a triple outlet pump, one outlet forcing oil to the main and connecting rod bearings, another to a spray in the crankcase while the third forces an oil spray into the supercharger, causing the incoming mixture to be saturated with oil before entering the cylinders. This eliminates the early practice of mixing oil with the gasoline for two-stroke motors which has been found to cause carburetor trouble on account of the heavy oil necessary for air-cooled motors filling up the jets of the carburetor.

An Early Static Radial Engine.—Some of the designers of early engines incorporated many features that were used in later engines. The engine shown at Fig. 905 included in its design an induction system that is now recognized as the best for large radial engines and also had a form of cowling built integrally that recent tests and development by the National Advisory Committee for Aeronautics has demonstrated to be an almost ideal form for radial air-cooled engines and to greatly reduce drag.

The Smith radial air-cooled engines were designed and built by Mr. John W. Smith of the Static Engine Company of Philadelphia, Pa. As a means of reducing weight through the omission of large counter-balances, ten cylinders were evenly disposed in a single plane about a two-throw crankshaft. Five slipper type connecting rods with "H" sections operated upon each crankpin. Since the plane of the cylinders was midway between the crankpin centers, the axes of the rods in each set were inclined to the

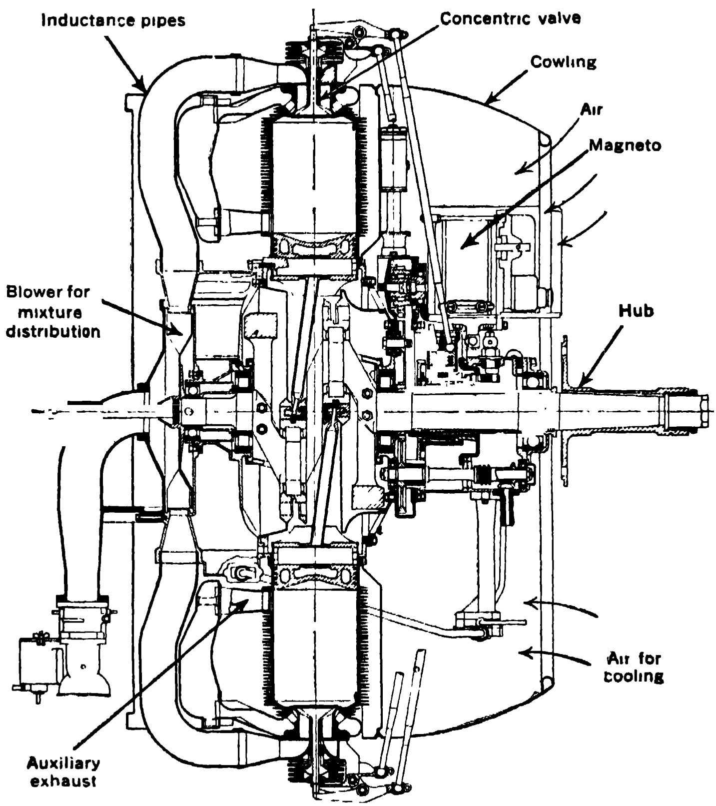


Fig. 905.—An Experimental 300 Horsepower Ten-Cylinder Smith Static Radial Engine Designed Some Years Ago Had Rotary Mixture Distributor and Very Effective Cowling Built Into the Engine.

plane of rotation. The steel cylinders had integral cooling flanges, and concentric type valves were fitted co-axially in the head and operated by two push rods and rockers. A hole in the cylinder wall near the end of the stroke served as an auxiliary exhaust port. The engine was throttled by controlling the closing of the inlet valve in relation to piston position. The principal feature of the Smith engine was the induction system, which consisted of a rotor with blades turning at crankshaft speed in a crankcase

compartment connected by induction pipes leading to all ten cylinders. The pipes extended into the mixture collecting compartment for a short distance to prevent condensation draining into the lower cylinders. The action of the rotor was to break up liquid globules and provide a uniform mixture delivery. The engine shown had a total displacement of 1,543.7 cubic inches and was designed to develop 300 horsepower at 1,600 r.p.m. The bore was 5.5 inches, the stroke was 6.5 inches and was designed to weigh about 3.36 pounds per horsepower. Concentric inlet and exhaust valves were used, the inlet seating into the exhaust. Trunk type cast-iron pistons were used. The readers attention is directed to the liberal use of ball and roller bearings throughout. The design can be criticized because

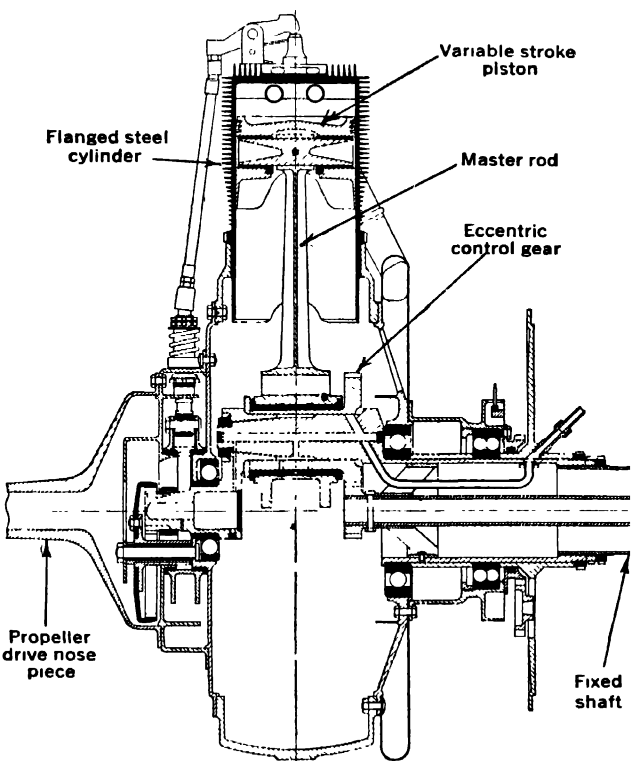


Fig. 906.—The Damblanc Rotary Radial Air-Cooled Four-Cycle Engine Incorporated the Distinctive Feature of Having Mechanism to Vary the Piston Stroke and Compression of the Engine.

of the use of off-set or angularly placed connecting rods and it is doubtful if the shoes at the crankpin ends of the connecting rods were adequate in size for endurance. The engine had a number of very interesting refinements worked into it, as auxiliary exhaust ports at the base of the cylinders

discharging into the exhaust pipe disposing of the gases from main exhaust in the cylinder head. This design was very commendable, even in the light of our present knowledge and showed that the designer had a good knowledge of the features of design necessary in radial air-cooled engines.

Variable Compression Rotary Engine.—An expedient sometimes advised by engineers to avoid the use of supercharging at altitudes is to use variable compression within the control of the pilot, the idea being to operate at low altitudes and dense air with a lower compression than at high altitudes where the air is thinner. A number of mechanisms have been designed to accomplish this object, but experience has proven that the effect is not the same as with a supercharger and that full charges can be obtained best by pumping in the mixture by a separate pump, rather than depending on the pumping effect of the engine piston to fill the cylinder. Such engines that have been designed around the principle of variable compression have not received practical application.

The Damblanc eleven-cylinder variable compression rotary engine shown at Fig. 906 was built in France during 1918. The bore is 126 millimeters (4.96 inches), the stroke 150 millimeters (5.91 inches), and the total displacement 1,256.09 cubic inches. The effective horsepower is stated to be 240, the useful horsepower 220, and the fuel consumption .573 pounds per useful horsepower-hour. The normal compression ratio is 4.8 to 1 and the maximum compression ratio seven to one, the variation being accomplished by changing the length of the stroke. An eccentric bushing on the crankpin is turned through gears by a shaft extending through the hollow crankshaft. The single-throw crankshaft is made in two major parts and mounted on ball bearings. Steel cylinders with integral cooling fins are fitted with liners and held in place by threads and lock nuts. The single inlet and exhaust valves of each cylinder are operated through push rods and rocker arms. The connecting rods are of the articulated type, and the pistons are fitted with three rings. The bushing for the piston pin is locked in the rod. The ignition is supplied by two magnetos. The dry weight is reported to be 441 pounds, and the outside diameter 40.16 inches.

Double Acting Rotary Engine.—Another principle that has been attractive to mechanical engineers and designers, especially those familiar with steam engine practice, has been the double acting engine wherein useful work is produced on both sides of the piston.

Messrs. Demont of Puteaux, France, have constructed several rotary engines, the first of which appeared as early as 1896. An interesting Demont engine, exhibited at the Paris Aero Show of 1913, shown at Fig. 907, was a six-cylinder double-acting air-cooled rotary model rated 300 horsepower at 2,000 r.p.m. The low weight power ratio of .73 pounds per horsepower was claimed. The bore was 175 millimeters (6.89 inches), the stroke 80 millimeters (3.15 inches), and the total displacement 704.7 cubic inches. The overall diameter was approximately 30 inches. The crankshaft was fixed and the crankcase and cylinders rotated about it upon ball bearings, an external ball bearing being provided at the propeller end to relieve the crankshaft of any bending load due to overhanging weight. The exhaust gases were disposed of in front. As the engine was double acting, two combustion-chambers had to be provided and inlet and exhaust valves placed at both upper and lower ends of the cylinder. The valves were

placed parallel to the crank axis and were actuated by rocker shafts parallel to the cylinder vertical axis. Twelve cams mounted on a sleeve in the nosepiece turned on the crankshaft and were driven at half engine speed by an epicyclic or planetary gear arrangement.

The construction of the working piston and the trunks on either side of it is worthy of special comment. The trunks were fitted with rings and acted on crosshead guides. An internal cooling action was derived by the circulation of air inside the piston and crankcase, though this must have

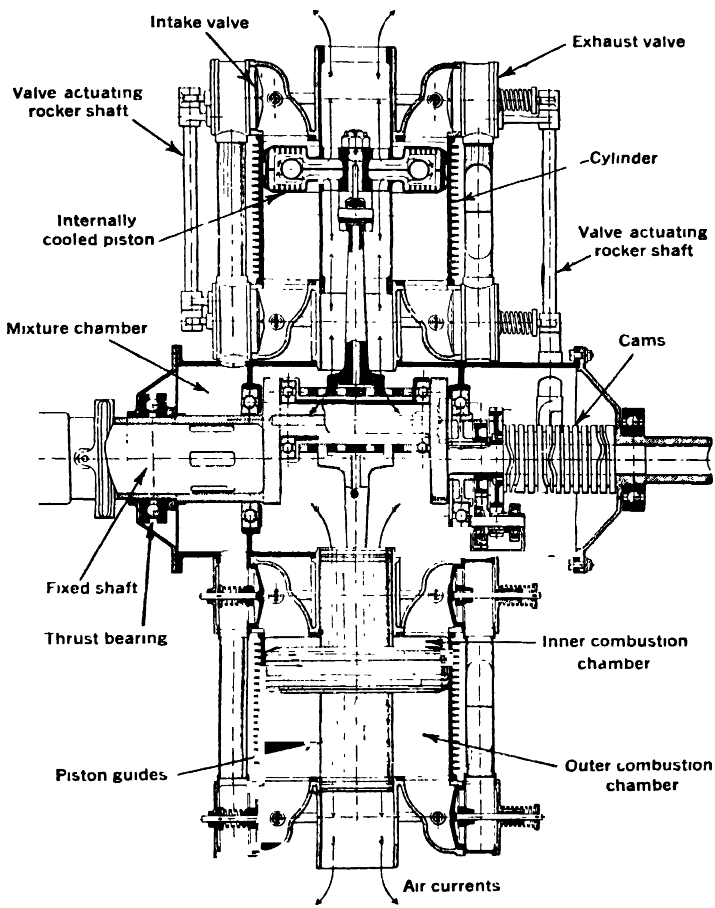


Fig. 907.—The Demont Engine Was an Unusual Double Acting Rotary Type Using Air-Cooled Cylinders Working on the Four-Cycle Principle.

provided an avenue of escape for considerable lubricating oil as the engine revolved. The air flow was assisted by centrifugal action due to cylinder rotation about the crank axis and a baffle plate was placed in each working piston to direct the air to the surfaces having the most heat. The connect-

ing rods were made hollow and the crankpin ends were forked, each having a different width and were strung along a bushing that was supported from the crankpin by two ball bearings. This arrangement provided that all the cylinders could be kept on the same plane, greatly simplifying the valve action. In this engine, six impulses occurred at equal intervals during each revolution. A single high tension, two spark magneto was driven at three times the engine speed and a sparkplug was placed in each valve pocket to give two spark ignition. The fuel mixture was supplied by a mixing device attached to the fixed crankshaft at the anti-propeller end and passed through a series of ports into an annular chamber surrounding the enlarged crankshaft. It was supplied to the valves by hollow tubes joining the valve chambers to the mixture collecting annulus.

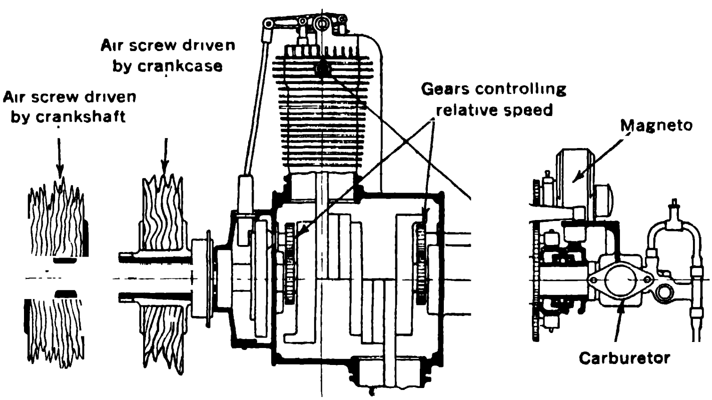


Fig. 908.—The E.J.C. Engine Illustrated Above Was Known as a Double Rotary Because the Crankshaft Turned in One Direction and the Crankcase and Cylinder Assembly in the Opposite Direction.

Double Rotary Engines.—Most rotary engines have a fixed crank and rotary cylinders but some designers have attacked the problem in a different manner and have had both the cylinders and crankshaft revolve, at different speeds and opposite to each other.

The E. J. C. engine shown at Fig. 908 was a six-cylinder air-cooled double-rotary type of 100 millimeters (3.94 inches) bore and stroke. Two propellers were used, one supported to the crankcase and turning normally at 800 r.p.m. and the other attached to the crankshaft and turning at 1,200 r.p.m. in the opposite direction. This gave a relative speed of 2,000 r.p.m. at which the engine was rated 60 horsepower. The weight was stated to be 185 pounds, or 3.08 pounds per rated horsepower. The position of the cam plate and high tension distributor was controlled by planetary gearing at each end. Plain type connecting rods were arranged side-by-side in threes on each of the two crankpins. Both valves were located in the cylinder head and controlled from the cam ring by push rods and rockers. A pipe to the inlet valve of each cylinder directed the mixture from the crank compartment which was supplied by a carburetor mounted on the end of the hollow crankshaft. A ten-cylinder 100-horsepower engine of the

same type is reported to have been built. Such engines are not popular for various reasons. There is considerable mechanical complication and the use of two airscrews mounted so there is mutual interference is not desirable or efficient.

Barrel Type Engines.—A compact cylinder arrangement is obtained by barrel type engines and a number of designs have been worked out and tested, both in this country and in Europe. The Macomber engine shown at Fig. 909 is an American design having seven air-cooled cylinders with their axes parallel to each other and to a central shaft. These engines are radial engines, the difference between them and the types ordinarily used being the horizontal disposition of the cylinders. A peculiar "wobble" plate mechanism replaces the usual crankshaft arrangement. Ball and socket

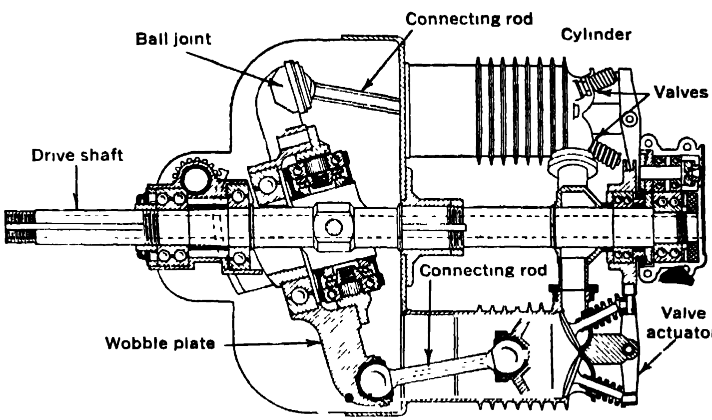


Fig. 909.—A Typical Example of a "Wobble" Plate or Barrel Type Engine, Known as the Macomber, Was an Air-Cooled Rotary Form.

joints are placed at each end of the connecting rods joined to the pistons and the angularly disposed plate which revolved with the cylinders. The pistons are reciprocated because of the angularity of the wobble plate. Special means were provided for varying the angle of the wobble plate, thereby effecting a change in the length of stroke and the compression ratio. Ball bearings were used throughout. The valves were located in the cylinder head, the inlets nearest the center and the exhausts to the outside, and operated from a single rocker, pivoted between them, which had one end sliding in a central grooved cam. It is stated that the "wobble" plate mechanism has greater power loss than the usual crankpin arrangement and as a consequence the mechanical efficiency of such engines is considerably less than the radial types having vertically radiating cylinders and the usual crankpin. The mixture is introduced through the hollow driveshaft, which communicates with a small annular chamber to which the inlet valve cages are connected by short pipes. This type of engine was applied to an automobile but the writer has no record of its use in an airplane. No performance figures are available.

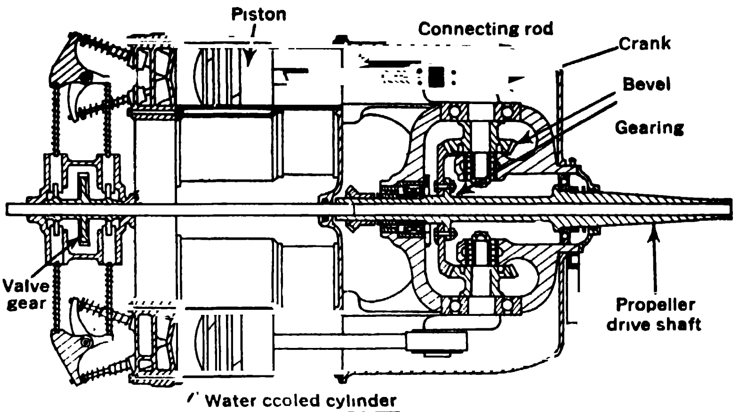


Fig. 910.—The Cleveland Aviation Engine Was an Unusual Barrel Type that Used Short Cranks and Bevel Gearing Instead of a "Wobble" Plate.

Another type of barrel engine has radially placed cylinders in horizontal relation but instead of the "wobble" plate mechanism, the pistons are reciprocated by short cranks, driving a central shaft through bevel gearing as indicated at Fig. 910 The Cleveland engines, designed by Walter C. Willard, were water-cooled barrel types planned so that many of the same parts could be used on a number of sizes ranging from 100 to 600 horsepower. The Model 4 described and shown at Fig. 910 was rated at 150 horsepower. This was a six-cylinder engine of five inch bore, six inch stroke, and 706.86 cubic inches total displacement. The propeller speed was reduced to one-half that of the crankskaft, thereby permitting the cams to be mounted upon the propeller shaft. There were six single-throw crankshafts having bevel gears meshing with a large "bull gear." The engine was lubricated by feeding oil on the "bull gear" where it was thrown about

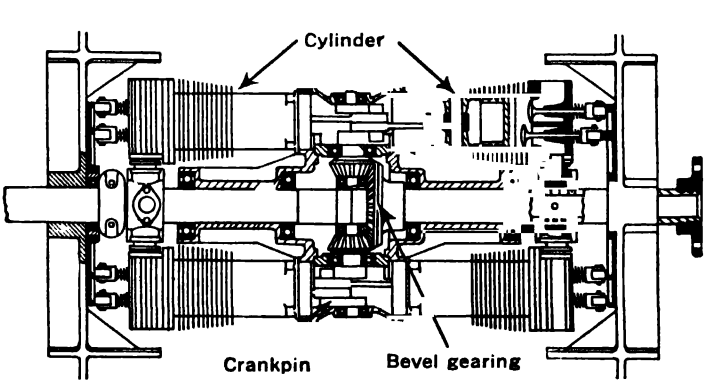


Fig. 911.—The Experimental Wherry Engine Was a Rotary Type Having Opposed Air-Cooled Cylinders so Arranged that it Was a Double Barrel Form.

so as to properly lubricate all the other parts. Ball bearings were used throughout. A combined cylinder head and intake manifold was cast from aluminum, while each cylinder barrel was of steel tubing with the sparkplug bosses and water jackets welded in place.

Still another form of double barrel engine is shown at Fig. 911. This shows the Wherry, an experimental air-cooled rotary barrel type engine constructed in England during 1916. Opposed cylinders, each pair of cylinders having the pistons reciprocated by a single crankpin and with overhead valves are placed around the central shaft. The valves are actuated by cam rings, against which roller followers mounted on the valve stems bear directly. No barrel type engines are used at the present time for either airplanes or automobiles and these had the same disadvantages as the usual form of rotary engines that militated against their practical application.

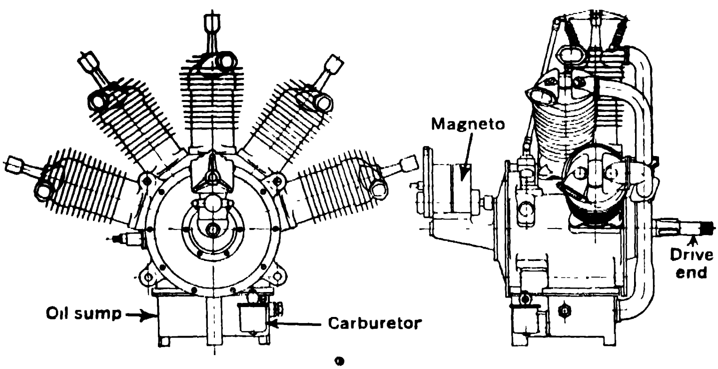


Fig. 912.—The R.E.P. Fan Type Motor Had Five Air-Cooled Cylinders Spread Out as Shown Above the Crankshaft.

Fan Type Engines.—An arrangement for stationary cylinder motors that was formerly popular is illustrated at Figs. 912 and 913. These air-cooled fan type engines were constructed by R. E. Pelterie in France as early as 1910. This inventor is also credited with the design of the modern stick control system used on most modern light and medium capacity airplanes. A five-cylinder engine, rated twenty horsepower at 1,400 r.p m., had an 85 millimeter (3.35 inch) bore, 95 millimeter (3.74 inch) stroke, and a total displacement of 164.8 cubic inches. The cylinders were made from cast iron with integral cooling fins, and were so staggered that all five operated about a single-throw crankshaft. The complete weight of this engine was stated to be 82.5 pounds, or 4.12 pounds per rated horsepower.

A seven-cylinder fan type, with cylinders of the same dimensions and therefore having a total displacement of 230.72 cubic inches, was rated 30 horsepower at 1,400 r.p.m. Four cylinders were forward and three to the rear, each with articulated connecting rod assemblies which worked upon a two-throw crankshaft. The weight was stated to be 114.5 pounds, or 3.81 pounds per rated horsepower. A ten-cylinder fan type engine, a double form of the twenty horsepower model and having a total displacement of

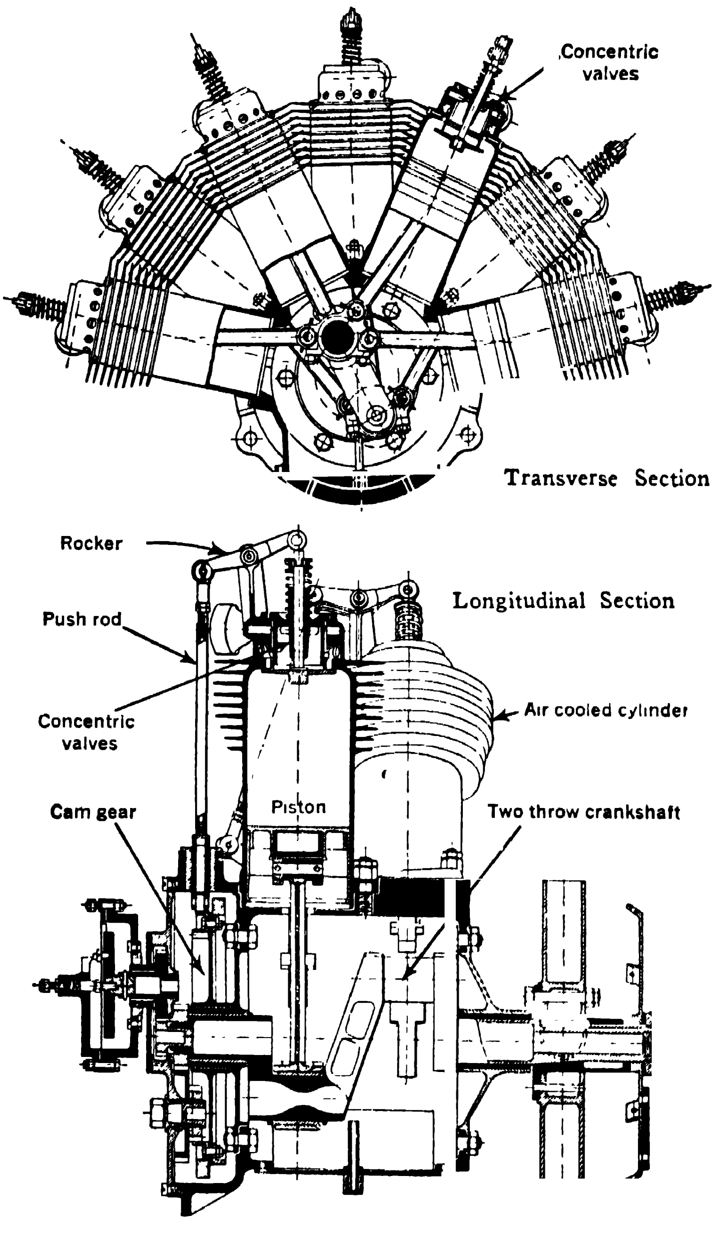


Fig. 913.—Transverse and Longitudinal Sectional Views of the Seven-Cylinder R.E.P. Air-Cooled Fan Type Motor.

329.6 cubic inches, was rated 40 horsepower at 1,400 r.p.m. This engine employed a two-throw crankshaft, and was fitted with a double magneto and two carburetors. The weight was said to be 158.5 pounds, or 3.96 pounds per rated horsepower. The double form of the 30 horsepower model, with fourteen cylinders and a total displacement of 461.44 cubic inches, was rated 60 horsepower at 1,400 r.p.m. and said to weigh 216 pounds, or 3.6 pounds per rated horsepower.

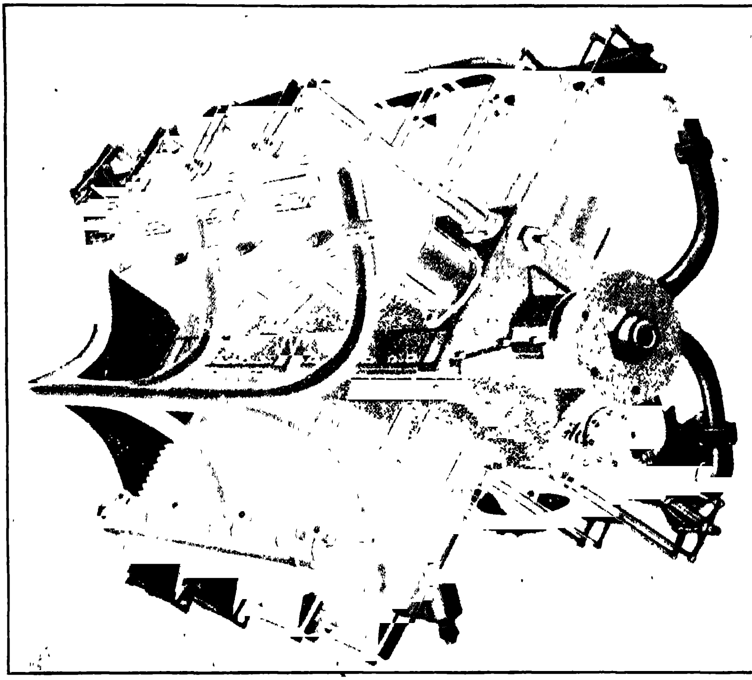


Fig. 914.—A Sixteen-Cylinder Air-Cooled X Form of Engine Known as the Viking Provided a Compact Cylinder Arrangement that Lent Itself Well to Direct Cooling.

X Type Air-Cooled Engine.—The arrangement of cylinders around the crankcase in the form of an X lends itself very well to engines having an even number of cylinders such as eight, twelve, sixteen or twenty-four. The angle is not always 90 degrees between cylinders, however, some engines having 45 degrees between the banks comprising the upper and lower assemblies and 135 degrees between the center lines of the right and left upper and lower cylinders respectively. If the angle between the cylinders at the top and bottom of the X is 60 degrees, then the angle between the banks at the side is 120 degrees. The symmetrical form shown at Fig. 914 has all banks of cylinders separated by an angular distance of 90 degrees. The engine shown was built in 1919 at Detroit, Michigan. The arrangement of cylinders lends itself well to air cooling. The Viking engine had a 3.25-inch bore, a four-inch stroke, and a total displacement of 530.88 cubic inches; and was said to develop 140 horsepower at 1,600 r.p.m.

The cylinders with integral cooling flanges were constructed individually from semi-steel, and attached to the aluminum crankcase by four flange bolts and four long binding bolts. The crankshaft was of built-up construction, annular ball bearings being used throughout. There were eight crank-throws, eleven main bearings, and sixteen connecting rod bearings since the conecting rods were arranged side by side on the crankpin. A camshaft, situated in both upper and lower Vees, operated the inlet and exhaust valves in each cylinder head through push rods and rockers. Each valve had a clear opening of 1.4375 inches and a .3125 inch lift. The pistons were made

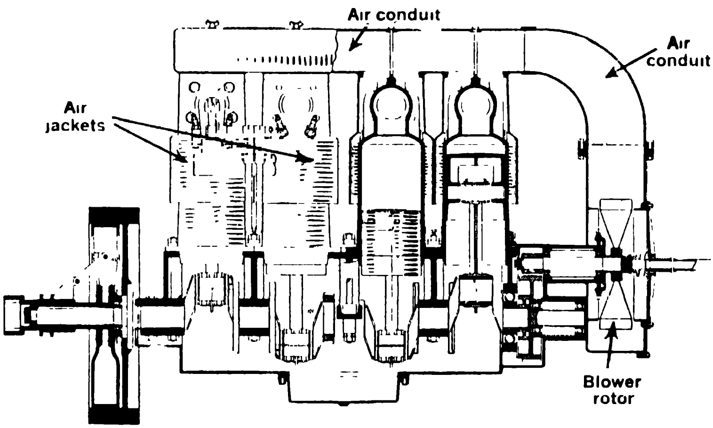


Fig. 915.—The Frayer-Miller Blower Cooled Automobile Engine Was the Parent Type of the Pipe and Renault Air-Cooled Aviation Engines.

from aluminum. Lubrication was provided by spray from the upper hollow camshaft that was supplied with oil under pressure from a pump. Another pump was employed to scavenge the system, and the ignition was furnished by Dixie magnetos. The total weight of the engine (completely equipped) was reported to be 306 pounds, or 2.83 pounds per rated horsepower. The fuel consumed per hour was said to be approximately 30 pounds at 1,400 r.p.m., and 36 pounds at 1,600 r.p.m.

Engines With Integral Cooling Systems.—The simplest form of self-cooled engine is that air-cooled form having a blower to produce an air blast around the cylinders. This construction makes it possible to mount the engine out of the propeller slipstream, which may be desirable in some powerplant locations, such as for wing or fuselage interior mounting. The writer feels sure the reader will be interested in the early engine shown at Fig. 915, which illustrates the Frayer-Miller automobile engine with a geared drive blower. While this form of engine was not applied to airplanes, it served as a model for the Pipe and Renault aircraft engines and all other types that force a cooling air blast through special conduits and cylinder jackets which is produced at considerable pressure by the rotary fan.

Some designers of water-cooled engines built their motors with the radiator for cooling the water attached directly to the water jackets. One of these is shown at Fig. 916. This method of construction was practical with in-line motors when it was customary to expose the engine to the air stream but it would not be favored at the present time when every effort is being made to reduce the parasitic resistance by cowling in all possible parts of the powerplant. The Grégoire four-cylinder vertical water-cooled engines, one of which is shown at Fig. 916, were built in France in 1910.

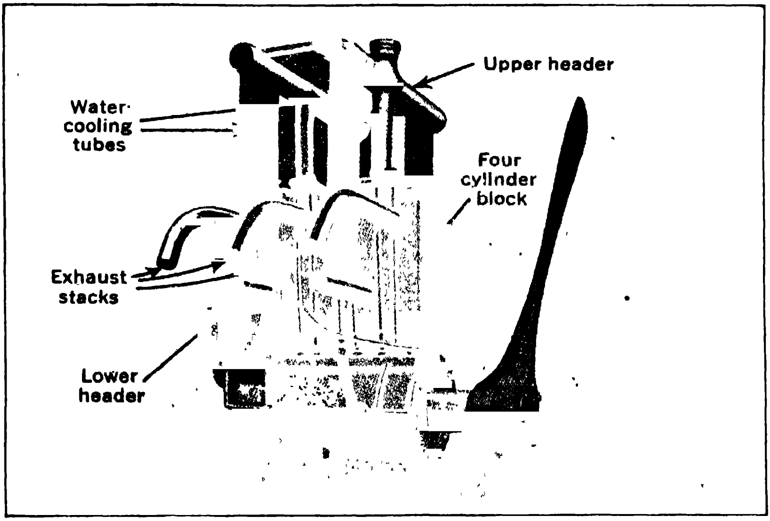


Fig. 916.—The Early Grégoire Four-Cylinder Water-Cooled Engine Had Thermo-syphon Cooling and Integrally Installed Water Radiators.

An interesting feature of these designs was the thermo-syphon circulating system and the integral radiator which reduced the amount of water to be carried to a minimum. The radiator consisted of four banks of small copper tubes terminating in a header at the top and bottom, the forward sections having two rows of tubes and the rear section only one. The upper header extended outward for a distance across the cylinder heads and received the water from a connection close to the valves while the lower headers were attached at right angles to the lowest part of the jacket. The smaller engine was rated 26 horsepower at 1,500 r.p.m. and reported to weigh 174 pounds, or 6.6 pounds per rated horsepower. The bore was 92 millimeters (3.62 inches), the stroke 140 millimeters (5.61 inches), and the total displacement 228.08 cubic inches. The larger Grégoire engine was rated 51 horsepower at 1,000 r.p.m. and reported to weigh 242 pounds, or 4.7 pounds per rated horsepower. The bore was 130 millimeters (5.12 inches), the stroke 140 millimeters (5.51 inches), and total displacement 453.44 cubic inches.

The Salmson Z9 engine, which is shown in longitudinal section at Fig. 917 was a form that was specially adapted to mount the radiator as part of the engine because the radial arrangement of the cylinders made it possible to cowl in the engine and start the cowling at the radiator. The Z9

model was one of the most efficient of the French engines developed during the war. This engine had nine cylinders of 4.92 inch bore and 6.69 inch stroke. The piston displacement was 1,146.42 cubic inches. The compression ratio was 5.4 and the engine delivered 230 horsepower at 1,500 r.p.m. and 280 horsepower at 1,650 r.p.m. Fuel consumption was .495 pounds per

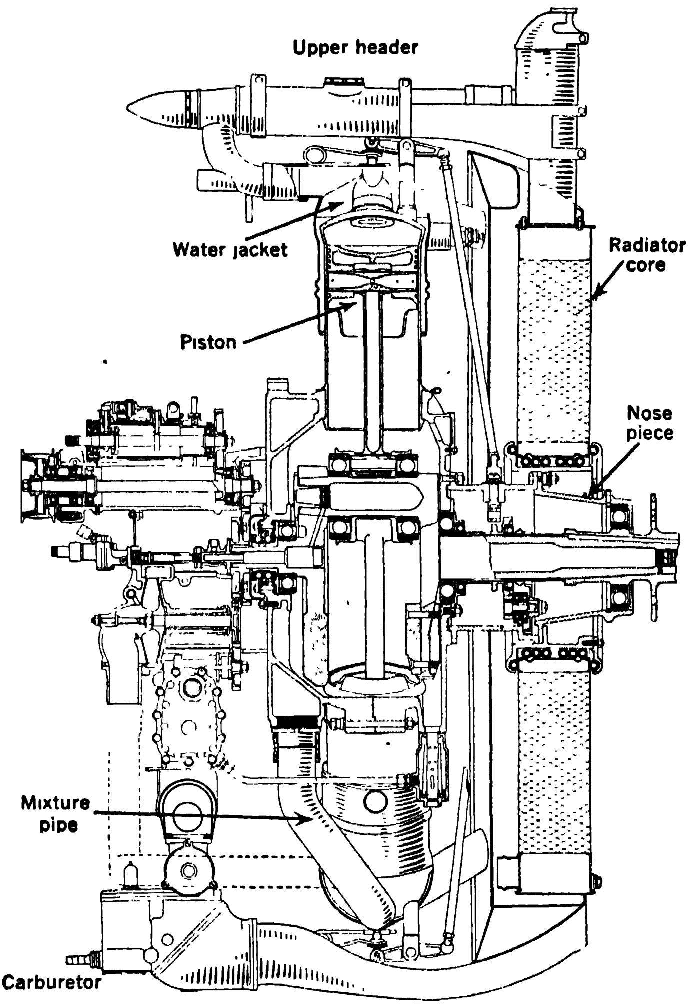


Fig. 917.—Longitudinal Sectional Elevation of the War-Time Salmson Static Radial Water-Cooled Engine, Model Z9 Had the Water Cooling Radiator Mounted on and Concentric with the Engine Nose Piece.

horsepower. The engine weight was approximately 475 pounds. The steel cylinders had sheet steel jackets welded on and were held between the halves of the vertically divided crankcase by flanges machined on the

cylinder. The cylinders were pulled up tightly against the crankcase by wedging rings. The inlet and exhaust valves were slightly inclined in the cylinder head, and operated through push rods and rockers by three inlet and three exhaust cams turning in the direction of the crankshaft at one-fourth its speed. The valve timing was as follows: the inlet opened on top center and closed 55 degrees late; the exhaust opened 65 degrees early and closed on top center. Dual ignition was supplied by two nine-cylinder magnetos. Claudel or Zenith duplex carburetors furnished the mixture. The oil was circulated by two oscillating plunger pumps; the small plunger forced oil to the bearings under pressure and the large one was used for scavenging.

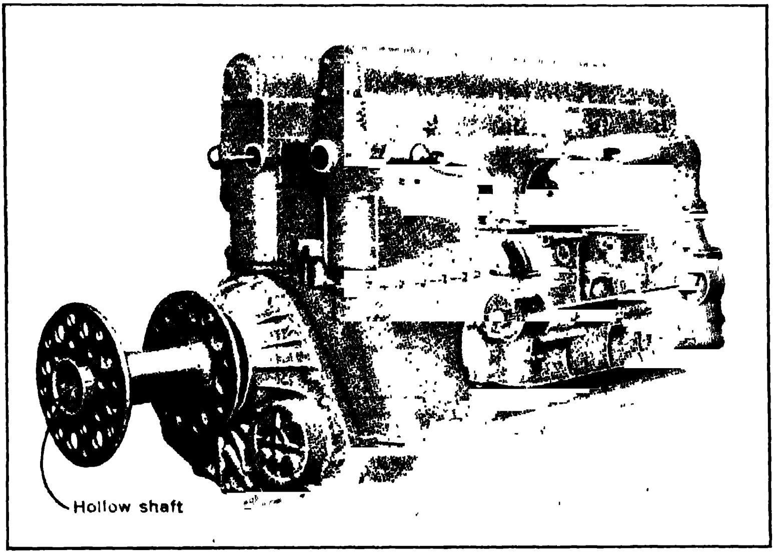


Fig. 918.—The Bugatti Sixteen-Cylinder Water-Cooled Engine with Hollow Propeller Driveshaft to Permit of Firing a Cannon Through it.

A double form of the Z9 model, with eighteen cylinders of 2,292.84 cubic inches total displacement, was normally rated 500 horsepower at 1,600 r.p.m. and 560 horsepower at 1,700 r.p.m. The compression ratio was 5.4. The fuel consumption was said to be .485 pounds per horsepower-hour, and the oil consumption .086 pounds per horsepower-hour. The weight was stated to be 1,000 pounds, and the overall diameter 39.5 inches.

Engines With Built-in Cannon.—A number of engines have been designed for military use that are intended for mounting at the front of the fuselage with a hollow propeller shaft extending clear through the engine from front to rear, the bore being of sufficient caliber for a small shell. The breech block mechanism is carried at the rear or anti-propeller end where it can be reached by the airplane pilot or gunner. Such guns are aimed by aiming the entire airplane. It is stated that Guynemer, the French ace, obtained many of his victories with an airplane mounting such an engine.

The sixteen-cylinder Bugatti engine shown at Fig. 918 and in transverse section at Fig. 919 is an engine of this type. The Bugatti engines were

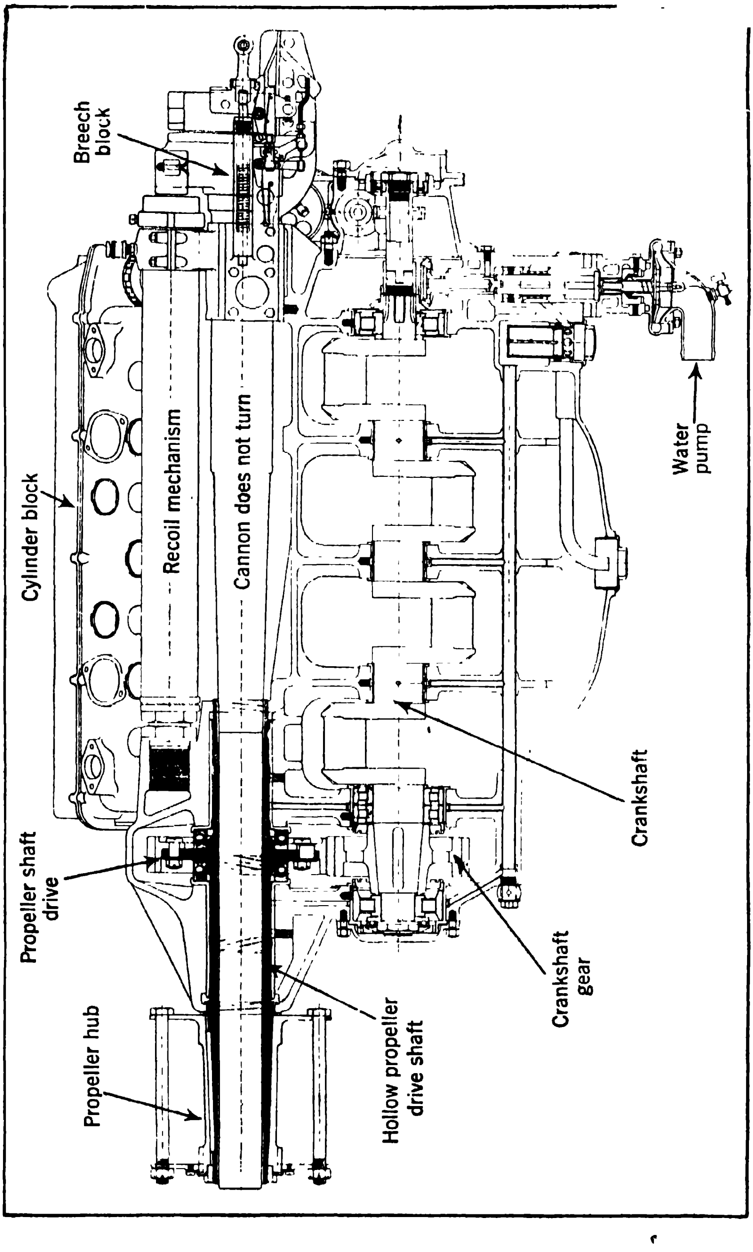


Fig. 920.—The Hispano-Suiza 220 CV "Cannon" Type Eight-Cylinder "Vee" Aviation Motor with Hollow Propeller Driveshaft with Cannon and Recoil Mechanism Forming Part of the Engine Assembly.

originally designed and built in France during the war by *Ettoire Bugatti*, a well-known automobile designer. The first engine was an eight-cylinder all-in-line type fitted with reduction gears. There was found to be no need for an engine of this form, so a sixteen-cylinder model was built with two all-in-line eights mounted upon the same crankcase. The two crankshafts were geared to a common central propeller shaft, which was made hollow to permit the firing of a French 37-millimeter cannon mounted between the two sets of cylinders as shown in the transverse sectional view.

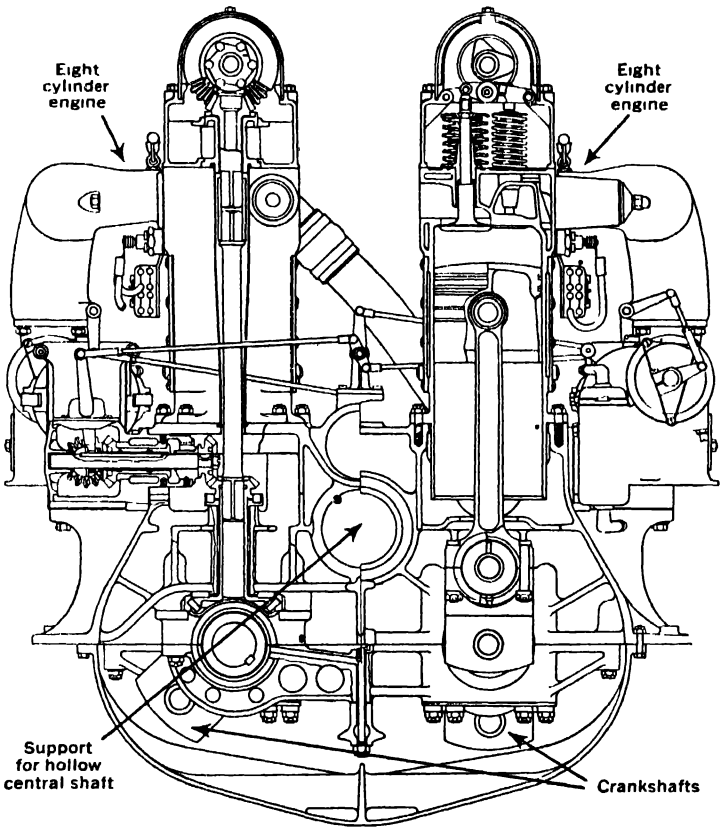


Fig. 919.—The Transverse Section of the Bugatti Engine Showing Arrangement of Two Banks of Vertical Cylinders at Each Side of a Centrally Disposed Propeller Driveshaft, a Very Unusual Arrangement.

The sixteen-cylinder vertical twin Bugatti engine was formed from the cylinder blocks of the eight-cylinder model. The total displacement was 1,484.29 cubic inches, and the rated output 400 horsepower at 2,100 r.p.m. The dry weight was stated to be approximately 1,000 pounds. The approximate overall dimensions are: length 44.25 inches, width 24.8 inches,

and height 32.28 inches. Two crankshafts, similar to those used in the eight-cylinder engine, were geared to a common propeller shaft at a ratio of two to three. Four Zenith carburetors, each mounted on a manifold feeding four cylinders, were located on the outside of the cylinder blocks, two on each side as shown at Fig. 918. This type of engine would call for a slightly wider fuselage than the Vee type.

The Hispano-Suiza 220 CV. "Cannon" type engine shown at Fig. 920 received considerable practical service during the late war and the mechanism is clearly shown in the longitudinal sectional view presented. In the main essentials, the engine follows the conventional Vee type eight. The hollow propeller driveshaft is machined with clearance inside so the cannon barrel can slide therein and at the same time the propeller driveshaft can revolve while the cannon barrel remains stationary. The propeller shaft is driven by a pair of spur gears as shown and revolves in long plain bearings, though ball thrust bearings are mounted on either side of the driven gear hub. A hydraulic recoil absorbing mechanism is housed in the cylinder above the cannon.

QUESTIONS FOR REVIEW

1. Describe rotary two-cycle engine actions
2. What is a barrel type engine?
3. What does the "wobble" plate do in an engine?
4. What is a "double rotary" engine?
5. Describe two different types of aviation engines with integral cooling system
6. How did King-Bugatti engine differ from the conventional type?

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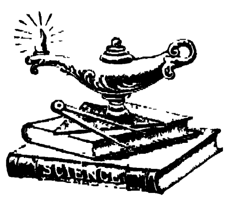

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